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NOTES ON THE OXIDATION OF JAMESONITE, SPHALERITE, AND TETRAHEDRITE.[1]

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INTRODUCTION.

SINCE publication of the paper[2] on the incipient oxidation of galena, the writer has been fortunate during his field work in securing partly oxidized sulphide ores of galena, sphalerite, tetrahedrite, and jamesonite. Thus, studies started on the incipient stages of galena alteration have been continued and extended to cover the oxidation or alteration of other sulphides. Work on the galena has merely confirmed the results of earlier studies wherein it was found that galena is more generally oxidized by air-water processes than by solutions of ferric sulphate; that the first product obtained by oxidation of galena is always anglesite; that replacement of galena by anglesite is mainly directed and controlled by cleavage directions in the galena; that there is an apparent absence of volume change from galena to anglesite; and, finally, that with an admixture of pyrite and chalcopyrite the oxidation of galena becomes more complex due to the formation of electrolytic cells between the different sulphides in contact with the oxidizing solutions, and that the attack on galena is greatly aided, whereas the oxidation of pyrite or chalcopyrite is much retarded.

[1] Published with the permission of the Director of the United States Geological Survey.

[2] Anderson, A. L.: "The Incipient Oxidation of Galena." ECON. GEOL., vol. 25, pp. 528–542, 1930.

Studies of the partly oxidized ores have been made mainly by means of polished surfaces. This method is satisfactory for obtaining the relative rates of oxidation of the different sulphides in contact and in establishing the controlling factors in replacement such as the effect of cleavage and crystal boundaries; but it is of little value in determining the composition of the secondary products of oxidation. For this reason the results obtained deal especially with the influence of one mineral upon another during the oxidation process and of the order in which each mineral is attacked. Such studies have confirmed the experimental work of Gottschalk and Buehler,[3] who early advanced the idea that minerals, when in contact and moistened, acted as batteries; that in mixtures of two sulphides there is a large increase in the solution of the one of lower potential while there is also a protective action exerted on the other, and that such contact may be an important factor in the general process of oxidation of the natural minerals. This same general process has been more extensively investigated by Wells,[4] who has also listed the order of attack on many minerals by oxidizing solutions, such order being due largely to electrolytic action. Studies of the minerals jamesonite and tetrahedrite were not included in these earlier investigations, nor did the work include actual study of the partly oxidized ores in the outcrop.

OXIDATION OF JAMESONITE

General Features.—Specimens of partly oxidized jamesonite were collected from near the surface of the veins at the Silver Hills mine in the Black Pine district of Cassia County, Idaho, not far north of the Utah line, while the writer was engaged in a study of the geology and mineral resources of eastern Cassia County.[5] At this locality the jamesonite occurs in association with sphalerite and tetrahedrite (freibergite) in a quartz-calcite

[3] Gottschalk, V. H., and Buehler, H. A.: "Oxidation of Sulphides." Econ. Geol., vol. 7, pp. 13–34, 1912.

[4] Wells, R. C.: "Electrical Activity in Ore Deposits." U. S. Geol. Survey, Bull. 548, 1914.

[5] Anderson, A. L.: "Geology and Mineral Resources of Eastern Cassia County, Idaho." Idaho Bur. of Mines and Geol., Bull. 14, 1931.

gangue. Pyrite is present in small amount and is rarely if ever recognized except in polished surfaces. The jamesonite is later than the other sulphides and forms replacement veinlets in them or replaces them in the form of idiomorphic laths or fibers. Much of the jamesonite occurs as divergent bundles of fibers. It is about as abundant as the tetrahedrite and sphalerite and all three tend to form granules and small masses or bunches in the vein quartz.

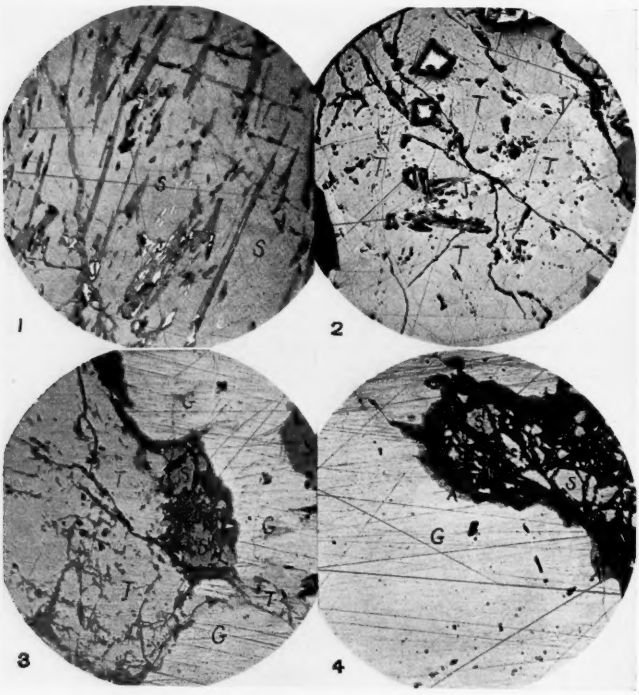
No jamesonite appears in the outcrop. Except for scattered small stains and crusts of malachite and azurite, usually with small residues of tetrahedrite, the outcrop is essentially free from secondary minerals, and even free from appreciable quantities of iron oxides. Except for vugs in the vein quartz there is little to indicate the presence of sulphide mineralization. Because of the rapidity of erosion, oxidation has gone to but slight depth. Partly oxidized tetrahedrite and sphalerite appear at less than a dozen feet below the surface. There is considerable porosity to depths of 40 feet below the surface, but not until the lower zone of secondary porosity is reached does the jamesonite make its appearance. It seems to be more readily removed from the oxidized zone than does either sphalerite or tetrahedrite, and signs of partial oxidation extend to much greater depth than in the case of any of the other sulphides.

Oxidation Products and Structures.—The most abundant secondary product after jamesonite is yellowish bindheimite ($2PbO.Sb_2O_5.nH_2O$). It forms fibrous pseudomorphs after the jamesonite and is comparatively abundant in the lower part of the oxidized zone. Crusting it, are scattered small patches and stains of "limonite." More extensive alteration has resulted in the complete to partial removal of the bindheimite, leaving behind empty casts dusted with "limonite." Apparently the bindheimite is not particularly stable or insoluble and is rather readily dissolved, the lead perhaps being deposited elsewhere as anglesite or cerussite and the antimony as the white and yellowish oxides. Such antimony oxides are present in the deposits but whether they have been derived from jamesonite or tetrahedrite, or both, is not

wholly certain. Sphalerite and tetrahedrite in contact with the partly altered jamesonite show little or no sign of oxidation.

Microscopic studies of the partly oxidized jamesonite give no definite clue as to the composition of the products obtained during incipient stages. Apparently the products are in part soluble, for vugs are of common occurrence.

Alteration of the jamesonite is directed for the most part along cleavages in the jamesonite and from crystal boundaries. Replacing veinlets are arranged mainly in rectangular sets. The contact between the jamesonite and its secondary products is extremely irregular or ragged or is more or less feathery in appearance.



Oxidation in the Presence of Admixed Sphalerite.—Microscopic studies reveal that the jamesonite oxidizes much more readily than does the sphalerite in contact with it. It is not uncommon to find sphalerite showing not the least sign of oxidation, yet with the jamesonite partly to wholly altered to secondary products. Casts of such jamesonite laths are illustrated in Fig. 1, in which the pseudomorphs retain only occasional grains of the original jamesonite. The sphalerite is wholly unaltered. Apparently oxidation must progress through the jamesonite before it can start on the sphalerite. This relation suggests that electrolytic action plays a role in the oxidation (although sphalerite is generally a poor conductor), that the jamesonite has a lower negative potential than does the sphalerite when the two are in contact and are moistened, and that the oxidation of the jamesonite is speeded while there is a protective action exerted on the

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FIG. 1. Photomicrograph of polished surface showing pseudomorphic laths after jamesonite in unaltered sphalerite (*S*). Some remnants of jamesonite (*J*) are retained in a few of the casts. The jamesonite oxidizes more readily than adjacent sphalerite and may even exert a protective influence on the sphalerite and retard its oxidation. × 56.

FIG. 2. Partly oxidized jamesonite laths (*J*) in unaltered tetrahedrite (*T*). Jamesonite seems even more readily oxidized in the presence of tetrahedrite than with sphalerite. In the same way the tetrahedrite is protected from oxidation so long as jamesonite is admixed with it. Such relations are probably explained by potential differences existing between the minerals when moistened and in contact, the one of lower potential being more rapidly oxidized and the one of higher potential retarded in its oxidation. × 56.

FIG. 3. Photomicrograph showing the relative rates of oxidation of sphalerite (*S*), tetrahedrite (*T*), and galena (*G*). Galena is scarcely oxidized; tetrahedrite is moderately veined by secondary products; and sphalerite is nearly completely oxidized. Electrolytic action is probably the cause for the different rates of attack. × 56.

FIG. 4. Photomicrograph showing oxidation of sphalerite (*S*) in contact with galena (*G*). The galena has a narrow border of secondary anglesite (*A*) and the outside of this border indicates the former contact between the galena and the sphalerite. This picture shows clearly the difference in the rates of the oxidation of the two sulphides. × 56.

other. Evidence of this is afforded in the enlarging of some of the alteration zones around sphalerite grains included in larger masses of jamesonite.

Oxidation in the Presence of Admixed Tetrahedrite.—A study of the specimens shows that the jamesonite is attacked even more readily when in contact with tetrahedrite than when in contact with sphalerite. Partly oxidized jamesonite laths in tetrahedrite are found to much greater depth below the apparent oxidized zone than are the partly altered laths in sphalerite. Specimens in which there is no sign of megascopic alteration of either sphalerite or tetrahedrite will show incipient to complete alteration of the jamesonite. A photomicrograph showing such a relation is illustrated in Fig. 2. This specimen was collected as an example of unaltered tetrahedrite ore. Crystal boundaries are not always followed during the alteration, although the ends of the laths are usually attacked first. It is probable that potentials again play a rôle. As will be discussed later, the tetrahedrite is less readily attacked than sphalerite and for this reason tetrahedrite should have a higher potential than sphalerite. Thus, a stronger cell action should be set up between jamesonite and tetrahedrite than between jamesonite and sphalerite and the alteration of the jamesonite in contact with tetrahedrite should be even more speeded. This has actual field verification, for the alteration of the jamesonite in contact with tetrahedrite has progressed farther and has gone to greater depths than that in contact with sphalerite.

Oxidation in the Presence of Admixed Pyrite.—The ore contains little pyrite, but wherever found it shows no sign of oxidation whether it is in contact with the jamesonite, sphalerite or tetrahedrite. It is the most stable of the group and according to the investigations of Gottschalk and Buehler [6] has the highest potential. For this reason its presence should not only speed the attack on the jamesonite but on the other minerals as well. It retains its original character even though entirely enclosed by the secondary products derived from the oxidation of the other sulphides.

[6] *Op. cit.*, p. 31.

Nature of the Oxidizing Solutions.—The scarcity of pyrite in the deposits and of "limonite" among the secondary products minimizes the possibility that iron salts have aided in the attack on the jamesonite and other sulphides. The dominant process is probably the air-water process, but because of the uncertainty in the nature of the secondary products formed during the incipient stages of oxidation no exact equation can be written. It is true that "limonite" occurs with the bindheimite and remains after the bindheimite has been removed, but this "limonite" is probably derived from the jamesonite itself. It has now become well established that iron forms an integral part of jamesonite and that its formula is $4PbS.FeS.3Sb_2S_3$. It is possible that the first products formed by the oxidation of the jamesonite are sulphates as expressed in the following equation:

$$4PbS.FeS.3Sb_2S_3 + 56O \rightarrow 4PbSO_4 + FeSO_4 + 3[Sb_2(SO_4)_3].$$

It is then likely that there is a recombination of the lead and antimony in the presence of water and a neutralizing environment and the hydrous oxide, or the lead salt of pyro-antimonic acid, bindheimite, results. The exact composition of bindheimite is in doubt and it may be an oxide, or, as suggested by Schaller,[7] may be the lead salt of pyro-antimonic acid, $H_4Sb_2O_7$. The sulphuric acid liberated during this action would probably be soon neutralized by the attack on the other sulphides or gangue minerals and the soluble products would be carried away.

OXIDATION OF SPHALERITE.

General Features.—Specimens of partly oxidized sphalerite admixed with galena and tetrahedrite from the Stokes district in Cassia County, Idaho, were studied in addition to those from the Silver Hills mine in the Black Pine district. Mineralization in the two districts is distinctly different and unrelated.[8] The deposits in the Stokes district are mainly fissure fillings in quartzite

[7] Schaller, W. T.: Mineralogic Notes, U. S. Geol. Survey Bull. 610, p. 105, 1916.
[8] Anderson, A. L.: Idaho Bureau of Mines and Geology, Bull. 14, pp. 103–141.

and are essentially quartz-galena veins with minor sphalerite and tetrahedrite. These belong to the mesothermal group of late Cretaceous or early Eocene age. On the other hand the deposits in the Black Pine district are replacements of limestone and belong to the epithermal base metal group of probably mid-Tertiary age. The essential features of oxidation have been the same in both districts and are not unlike those in other districts.

The occurrence and general distribution of the sphalerite in the upper parts of the deposits in the Black Pine district have already been adequately discussed. In the Stokes district as elsewhere the sphalerite shows marked tendency to depart from the oxidized zone and the partially oxidized sphalerite is found only in the very lowest part of the oxidized zone. It leaves little behind except "limonite" structures to record its presence.

Oxidation Products and Structures.—The oxidation products of sphalerite, together with the structure of the resulting limonitic types, have been admirably discussed by Boswell and Blanchard.[9] The first product formed from its oxidation is the sulphate. Its extreme solubility, 500 grams per liter of water, explains why the zinc sulphate does not remain in the cropping if waters circulate through the oxidized area. Its conversion to smithsonite or calamine and the relative insolubility of these minerals is well known.

Microscopic studies of the partly oxidized sphalerite reveal that the incipient alteration is strongly controlled by cleavage directions within the sphalerite. This results in both triangular and approximately rectangular nets. Replacement is usually more pronounced in one of the dodecahedral directions than in the others. Because of the solubility of the resulting sulphate a cellular structure is readily developed.

Oxidation in the Presence of Admixed Tetrahedrite.—In contact with tetrahedrite the sphalerite shows even more extensive alteration. Sphalerite grains or granules enclosed in the tetrahedrite may be almost wholly oxidized whereas the tetrahedrite

[9] Boswell, P. F., and Blanchard, Roland: "Oxidation Products from Sphalerite and Galena," ECON. GEOL., vol. 22, pp. 419–453, 1927.

in contact with it shows scarcely a sign of any attack. This relation is shown in Fig. 3, in which sphalerite is not only in contact with the tetrahedrite but with galena as well. Of the three it shows by far the greatest amount of alteration. Other specimens show such relations in the structure and width of secondary zones as to suggest that a cell set-up is again in force and that by this contact the oxidation of the sphalerite is speeded while the tetrahedrite is protected. Yet the contrast in the degree of oxidation between the sphalerite and tetrahedrite is by no means as great as between jamesonite and tetrahedrite or between jamesonite and sphalerite and for this reason it is probable that the potential difference between the sphalerite and tetrahedrite is not great. Of the two the tetrahedrite would have the higher potential and where in contact with sphalerite would tend to resist attack while at the same time the sphalerite would invite attack. Such tendencies are expressed in the specimens that were studied not alone from the Black Pine district but from the Stokes district as well.

Oxidation in the Presence of Admixed Galena.—Sphalerite shows the same behavior toward galena as it does toward tetrahedrite, but the difference between sphalerite and galena undergoing oxidation is greater than it is between sphalerite and tetrahedrite, and the attack on the sphalerite goes on at an even faster rate, whereas the galena is more strongly protected than the tetrahedrite under the same circumstance. This relation is brought out most strikingly in Fig. 3, where the three minerals are in contact. The galena shows scarcely a sign of oxidation whereas the tetrahedrite is moderately veined by secondary products and the sphalerite is almost destroyed. Further relations between the sphalerite and galena are exhibited in Fig. 4. Small remnant masses of sphalerite remain in the oxidized products whereas the galena shows only slight replacement by anglesite which has worked inward from the former galena-sphalerite contact. The width of the altered sphalerite or limonitic band is nearly four times that of the anglesite band. This indicates that when the alteration products from the sphalerite reach a certain thickness or width the cell is destroyed and the oxidation of each goes on

independently of the other. The cell set-up also explains why the galena tends to linger in the oxidized zone and associated sphalerite is so rare, for the presence of the galena speeds the attack on the sphalerite while at the same time the galena is protected from attack. This distribution, therefore, does not depend wholly on the relative solubilities of the lead and zinc sulphates.

Oxidation in the Presence of Admixed Pyrite.—Pyrite has the same effect on the oxidation of the sphalerite as it has on the jamesonite and most other minerals so far studied. Its presence actually speeds the oxidation of the sphalerite while it is itself actually protected from the attack of oxidizing solutions until such time as the intervening band of secondary products destroys the effectiveness of the cell set-up, when attack on it goes on independently. It is a common occurrence for the sphalerite to show much more extensive alteration about pyrite grains than about other minerals, probably because the pyrite has a higher potential than most other minerals and the electric currents generated are much stronger or much more effective because of the greater induced electromotive forces.

Oxidation in the Presence of Admixed Chalcopyrite.—Chalcopyrite has the same effect on the oxidation of sphalerite as has pyrite. According to Gottschalk and Buehler,[10] chalcopyrite has about the same potential as pyrite, and it should therefore behave similarly in respect to minerals of lower potential. Wells[11] shows, however, that chalcopyrite should be more rapidly oxidized than pyrite and that it is itself preceded by marcasite, covellite, pyrrhotite, and galena, in the order given. The writer[12] has also shown that chalcopyrite is less readily attacked than galena in admixtures of the two minerals. Therefore it is not surprising to find unaltered grains of chalcopyrite in much altered masses of sphalerite and that such alteration is especially extensive about the grains of chalcopyrite.

Replacement of Sphalerite by Covellite.—Veinlets and patches of covellite representing replacements of sphalerite occur in most

[10] *Op. cit.*, p. 31.
[11] *Op. cit.*, p. 70.
[12] *Op. cit.*, ECON. GEOL., vol. 25, pp. 533–537.

of the sections studied. Covellite as a replacement of sphalerite has been described by a number of writers, and mention of it now introduces nothing new. Its deposition has resulted from the interaction between sphalerite and copper sulphate solutions and the reaction may be expressed simply as follows:

$$ZnS + CuSO_4 \rightarrow CuS + ZnSO_4.$$

Such covellite may become stranded as the result of reintroduction of oxidizing solutions and left behind in the sphalerite oxidation products. Its occurrence is then the same as the "stranded" covellite borders in anglesite discussed by the writer in another paper.[13] Its potential is higher than that of sphalerite, and for this reason its presence speeds the attack of oxidizing solutions on the sphalerite while it is itself protected.

Nature of the Oxidizing Solutions.—Boswell and Blanchard[14] have discussed the nature of the oxidizing solutions and have indicated that the sphalerite may be oxidized either by air-water processes or in the presence of admixed pyrite by ferric sulphate solutions. For the first process the reaction may be written as follows:

$$ZnS + 2O_2 \rightarrow ZnSO_4.$$

This process is necessarily the active one in the Black Pine district because of the general absence or scarcity of "limonite" in the outcrop. Microscopic studies also fail to reveal the attack or the former presence of iron solutions.

The second process may be written as follows:

$$Fe_2(SO_4)_3 + ZnS + 3O + H_2O \rightarrow ZnSO_4 + 2FeSO_4 + H_2SO_4.$$

The ferric sulphate would be derived from oxidizing pyrite or outside sources. On contact with more oxygen the ferrous sulphate would oxidize to the ferric state and in a neutral solution would hydrolize, eventually yielding "limonite." This process has in part been active in the Stokes district, for some "limonite" is associated with the secondary zinc product.

[13] *Op. cit.*, ECON. GEOL., vol. 25, pp. 538–540.

[14] *Op. cit.*, pp. 444–450.

OXIDATION OF TETRAHEDRITE.

General Features.—The occurrence of tetrahedrite in the outcrop at the Black Pine district has already been cited. In other places examined by the writer the tetrahedrite tends to linger behind the other sulphides and to show only partial oxidation, especially true where there is not much "limonite," which in turn signifies that there was not much pyrite or other iron-bearing minerals among the primary sulphides. If "limonite" is abundant, the tetrahedrite apparently does not linger in the oxidized zone. This relation suggests that iron salts might have an important rôle in the oxidation of the tetrahedrite.

Oxidation Products and Structures.—The products obtained during incipient stages of oxidation are not readily recognized. Means other than study of polished surfaces are necessary for their identification. Limonite types derived from tetrahedrite have been discussed by Blanchard and Boswell.[15] Aside from the limonitic structures left behind after the leaching of the tetrahedrite, there are commonly (but not everywhere) local incrustations of antimony oxides, and scattered patches or crusts of malachite and azurite. In the Black Pine district the tetrahedrite occurs in the very outcrop and shows only partial oxidation. It is not accompanied by "limonite," but remnant masses are usually crusted with both malachite and azurite, and open cavities also show minor quantities of the yellow and white antimony oxides. When many of the specimens are examined in closer detail the tetrahedrite appears intimately admixed with covellite. Although the tetrahedrite from the Black Pine district is rich in silver and has a cherry-red streak, no secondary silver minerals were observed.

Alteration of the tetrahedrite seems strongly directed along crystal boundaries in the crystalline aggregates. There results, then, a triangular pattern or network of the secondary products in the tetrahedrite. This is most striking when the tetrahedrite has been replaced by covellite. There is apparently no volume

[15] Blanchard, Roland, and Boswell, P. F.: "Limonite Types Derived from Bornite and Tetrahedrite," ECON. GEOL., vol. 25, pp. 557–580, 1930.

change where covellite replaces the tetrahedrite, but where alteration has been otherwise the veinlets show much porosity. Alteration also tends to follow quartz-tetrahedrite boundaries. Admixed minerals again play an important rôle during the oxidation of the tetrahedrite, either aiding or retarding its oxidation. The effect of admixed jamesonite and sphalerite has already been described, the oxidation of the tetrahedrite being retarded in their presence.

Oxidation in the Presence of Admixed Galena.—It has already been pointed out (Fig. 3) that the tetrahedrite is more readily

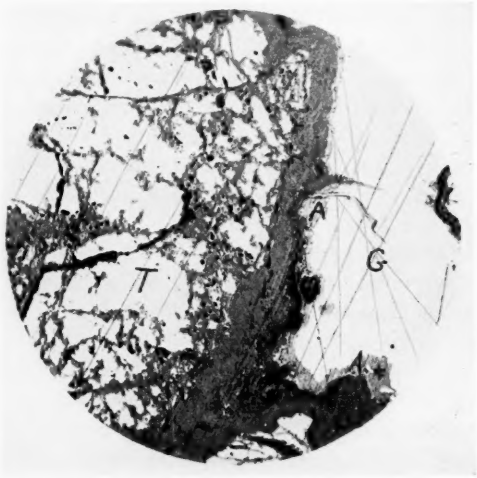

FIG. 5. Photomicrograph showing the difference in the rate and degree of oxidation of tetrahedrite (*T*) and galena (*G*). The galena has a narrow border of light gray anglesite (*A*) the outside of which denotes the former contact of the tetrahedrite and galena. This picture shows the ease with which the tetrahedrite oxidizes when in contact with galena. ×72.

oxidized than galena in contact with it, but the contrast is even more apparent in Fig. 5. Here a wide zone of secondary products lies between the galena and the tetrahedrite, most of the zone

composed of alteration products derived from the tetrahedrite, but part of it of anglesite. The anglesite forms a light colored border on the galena and shows clearly the former sulphide contact. The width of the anglesite border is about one fourth the width of the band of secondary products derived from the tetrahedrite and this relation might be used to work out the relative speeds of the oxidation of the two sulphides when in contact. It is probable, however, that a potential difference exists between the two minerals when in contact, and in the presence of oxidizing solutions, the galena having the higher potential and the tetrahedrite the lower, in which case the galena would be protected from oxidation as long as the cell remained effective, while the oxidation of the tetrahedrite would be speeded. But as the distance between the two sulphides would become greater as the band of secondary products increased in size the effectiveness of the cell would be destroyed and the attack on the galena would begin independently of the presence of the tetrahedrite. Such is probably the case in Fig. 5. According to Wells [16] there are counter effects in electrolytic action at every stage, and the speed of such action would under many conditions be limited by processes of diffusion. Referring again to Fig. 5, it will be seen that the alteration is not confined to the mineral contacts alone but extends in irregular veinlets through the tetrahedrite mass. In fact most of the alteration is within the tetrahedrite masses. On the other hand, the galena shows scarcely a sign of oxidation. It is possible that the potential difference between the galena and tetrahedrite is not as great as between the galena and sphalerite and for this reason the tetrahedrite shows more internal alteration, although the potential difference is sufficient to prevent oxidation of the galena. That tetrahedrite occupies a position intermediate between galena and sphalerite in its resistance or susceptibility to oxidation is apparent in all the sections studied and is strikingly exhibited in Fig. 3.

Oxidation in the Presence of Admixed Pyrite.—The electrolytic cell is not lacking between tetrahedrite and pyrite, for in general

[16] *Op. cit.*, p. 70.

the alteration zone in the tetrahedrite swells widely around grains and crystals of pyrite. The behavior is similar in every way to that exhibited between pyrite and galena, sphalerite, and jamesonite. Unquestionably the presence of pyrite greatly speeds the oxidation of the tetrahedrite. In every case where remnants of tetrahedrite or other sulphides mentioned above remain nearby, the pyrite does not show the least sign of alteration. Chalcopyrite behaves in a manner similar to that of pyrite.

Replacement of Tetrahedrite by Covellite.—Mention has already been made of the replacement of tetrahedrite by covellite. Such replacement is marked in the partly oxidized grains of tetrahedrite in the Black Pine district and is shown in lesser degree in the specimens from the Stokes district. The covellite tends to form triangular nets through the tetrahedrite and from its relations to oxidized products in the tetrahedrite proves that it is a supergene mineral and is not the result of hypogene replacement. The covellite seams or veinlets contain a central core of a grayish non-metallic mineral whose composition has not been determined but whose development is the result of the reaction by which covellite has been produced. Its quantity is much less than that of the covellite. Until the nature of this mineral is learned it is not possible to determine the composition of the solution and the mechanism of the reactions by which the covellite replaces the tetrahedrite.

Nature of the Oxidizing Solutions.—Tetrahedrite possesses insufficient sulphur to form fully oxidized sulphates of all its metallic constituents. According to Blanchard and Boswell[17] unless acid from associated oxidizing pyrite or other external source becomes available, complete oxidation of tetrahedrite does not occur. They give the following equation as the probable reaction in the oxidation of tetrahedrite:

$$4Cu_2S.Sb_2S_3 + 32O = 7CuSO_4 + Sb_2O_3 + CuO.$$

This leaves CuO unsatisfied, and since one molecule of pyrite is equivalent to $\frac{1}{2}H_2SO_4$, two molecules of pyrite would be required

[17] *Op. cit.*, ECON. GEOL., vol. 25, p. 577.

to complete the oxidation, thus:

$$CuO + H_2SO_4 = CuSO_4 + H_2O.$$

To substantiate these assumptions Blanchard and Boswell cite field relations where it has been observed that resistance of tetrahedrite to complete oxidation ordinarily coincides with little pyrite in or near the tetrahedrite occurrences; that complete oxidation usually coincides with more abundant pyrite (or its equivalent in acid attack) for the deposit as a whole, where conditions for thorough leaching are otherwise favorable. These relations are corroborated by the finding of the writer in the present studies, as is strikingly shown in the Black Pine district where the pyrite content is unusually low and the tetrahedrite lingers at the very surface.

ORDER AND RATE OF SULPHIDE OXIDATION.

Studies of incipient oxidation of the several sulphides have brought out especially the influence that one mineral may exert on another during the oxidation process, either to speed the oxidation or to retard it, such effects being due to potential differences existing between the minerals when in contact and moistened. In an earlier work [18] it was shown that galena oxidized more readily than pyrite, chalcopyrite, and covellite in contact with it and that the other sulphides at the same time were protected from oxidation; in fact the oxidation of galena was actually hastened by their presence. Similar conclusions have been derived in the present study in the case of jamesonite, sphalerite, and tetrahedrite, and the list may now be amended to include these minerals in their respective places.

As amended, beginning with the mineral which would be oxidized most rapidly, the list would show the minerals in the following order: jamesonite, sphalerite, tetrahedrite, galena, covellite, chalcopyrite, and pyrite. Any mineral in this list would thus be speeded in its oxidation when in contact with any mineral in the list that follows and conversely any mineral would be retarded in its oxidation when in contact with any mineral that precedes it on the list.

[18] Anderson, A. L., *op. cit.*, ECON. GEOL., vol. 25.

These studies explain why jamesonite does not appear in the outcrops even though it is as abundant as the sphalerite and tetrahedrite in the primary ore, why sphalerite has persisted in higher horizons in the oxidized zone than has the jamesonite, and why tetrahedrite appears at the very surface, although lack of sufficient pyrite has also prevented the complete oxidation of tetrahedrite. Pyrite may remain in the oxidized zone so long as these other sulphides have not been completely removed. Galena remains in the outcrop only because the coating or crust of insoluble secondary products resulting from the oxidation prevents access by fresh oxidizing solutions.

In time the writer hopes to study the incipient oxidation of all metallic minerals, singly and admixed, and so obtain a complete list of the minerals arranged in the order of their attack by oxidizing solutions.

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DIATOMACEOUS EARTH IN OREGON.

WARREN D. SMITH.

INTRODUCTION.

DIATOMACEOUS earth, or kieselguhr, has long been known to occur in Oregon in many localities, but only within the last few years has it become of commercial importance. This delay in exploitation has been due chiefly to the fact that the uses for this substance have not heretofore been so great and other localities in the United States were well able to supply market requirements. However, with the growing demands for insulating materials, it now seems as if the Oregon deposits would soon receive greater recognition.

So far as known, the Oregon diatomaceous deposits are all of fresh water origin and are of late Tertiary or Pleistocene age.

Very little recently published information is available on these deposits. Aside from some notes by Dr. A. C. Boyle, Jr.[1] and a few statements by V. L. Eardley-Wilmot,[2] little can be found in print.

Miss Margaret Ramsey, in June, 1929, presented a dissertation to the Department of Plant and Animal Biology of the University of Oregon on the subject, "A Study of Fossil, Freshwater Diatoms of Oregon." I am indebted to Miss Ramsey's dissertation for several important notes concerning early publications[3] on this subject.

As a result of some commercial work in the eastern part of the

[1] In a report to the chief engineer of the Union Pacific Railway. This report is included in U. S. Geol. Surv. Water Supply Paper 637–D, 1931, by H. T. Stearns.

[2] Diatomite. Can. Dept. of Mines Bull. 691, p. 102, 1928. See also an article by A. L. Lomax, School of Business Administration, Univ. of Oregon, on the production and marketing of this material, Commonwealth Review, Univ. of Oregon, XIII, No. 3, July, 1931.

[3] U. S. Exploring Expedition under J. C. Fremont (1843). Paper by J. W. Bailey and later papers in American Journal of Science (1857). Raborg, William A., U. S. Geol. Survey, Min. Res., 1886.

State in the Harper district, the writer has made some studies which have not yet been made public.

The principal deposits (Fig. 1) of commercial importance in the state at present are:

(1) Terrebonne, near Lower Bridge Deschutes River, central Oregon; (2) Harper, Eastern Oregon; (3) Jontura, Eastern Oregon. Other deposits of possible commercial value are located at: (1) Near Klamath Falls; (2) John Day River, 20 miles north

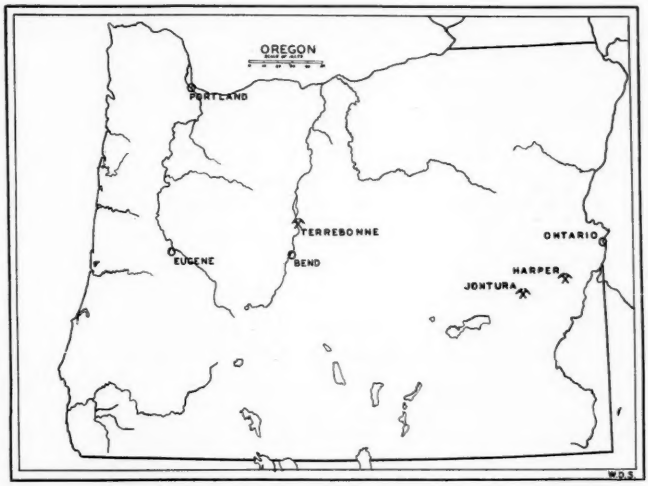

FIG. 1. General outline map of State showing location of deposits.

of Dayville; (3) Baker County, Tns. 13 and 14 S., R. 37 E.; (4) Union County, four miles southeast of Elgin on Indian Creek.

Diatoms, as is generally known, are minute single-celled organisms, algae belonging to the plant kingdom, which have tests of silica. In life they are either free-floating or attached in filaments to other substances. They are of two great classes—marine and freshwater. Their tests accumulate to such an extent as to make up deposits of hundreds of feet in thickness and form valuable deposits. Their association with petroleum deposits in

California has led some investigators to assume that they are an important source of oil. Because of this alleged connection, many persons in Oregon have assumed that valuable oil deposits may be found in Oregon near our own diatomaceous deposits. However, and with good reason, any such association here in Oregon has yet failed to be noted, and so far no oil has been found.

Diatomaceous earth in Oregon occurs for the most part in relatively undisturbed horizontal beds intercalated with volcanic ash, clay, and sand, all accumulations in lakes which formerly existed in structural and other depressions in the Tertiary lava flows of the State and, wherever studied by the writer, are post-Columbia or post-Snake River, that is, of Upper Miocene, Pliocene, and perhaps Pleistocene age.

THE HARPER DEPOSITS.

The principal deposits at this locality are located about 7 miles north and slightly west of Harper, and others are about 3 miles northeast of this town.[4] In all there are some thirty claims under the control of the White Earth Products Corporation in this group, near railway transportation.

The topography of the immediate country is marked by a broad alluvial filled flat bordering Malheur River, and long sinuous whitish or grayish escarpments some 200 feet or more above the valley floor, in which the diatomite and associated ash beds are exposed. The higher parts of this rim are capped with lava flows, which in places are found only as remnants.

The deposits are on the main highway from Harper to Westfall. Harper is located in a portion of the state having only about eight to ten inches of annual rainfall, hence one very important factor in the preparation of this material, that of low humidity, is quite favorable. The low humidity and frequent high winds, especially in summer, make it easy to prepare this material for the market at low cost because the cost of drying the material is reduced. However, some moisture is always retained by these porous tests, and has to be driven off by heat.

[4] Portions of Secs. 2, 3, 4, 9, 10, and 11, T. 19 S., R. 41 E. Willamette Meridian, and sec. 34, T. 18 S., R. 41 E. Willamette Meridian.

Formations.—The deposits lie in approximately horizontal beds that outcrop in a long sinuous erosion escarpment for many miles, capped in part by a rim of basalt. In many places this thin capping of lava has been removed.

A general stratigraphic column for the district is given in Table I, and the relationship to the lower-lying Snake River basalts is shown in Fig. 2.

TABLE I.

Formations	Thickness (Approx.)	Age
Alluvium	varying	Pleistocene and Recent.
Lava and tuff capping	1–50 feet	Pliocene (?)
Upper Diatomite Horizon	25–50 feet	
"Big Tuff"	50–100 feet	
"Lower Diatomite"	45–90 feet	
"Little Tuff"	4–6 feet	
Diatomite with clay, sand, and ash	Unknown	
Snake River Basalt	Unknown	Miocene

A detailed section, accurately measured, of the principal deposit and perhaps the best one of the entire group is given in Fig. 3. Before this section was made it was thought by many that the entire hill was diatomite. Below the workings near the bottom there is so much intercalated ash and clay that what appears to be valuable material is found to be comparatively worthless. Above the tunnel, however, there is forty feet of excellent and comparatively pure material.

The presence of the tuff and lava beds above are important from the mining standpoint. Where these are too thick, stripping cannot be employed and underground mining methods will be necessary, which, of course, will increase costs.

Structure.—At first sight these deposits seem to be undisturbed and flat-lying, but closer examination shows that in some places they are intensely folded, even plicated. In the main, however, they are gently undulating. There are also some minor faults involving throws of ten feet or more. Small displacements of a few inches to two or three feet are numerous.

The diatomite commonly has a conchoidal fracture, and much

of it can be sawn into desired blocks. Some bedding planes are present, and these will aid in excavation. A few small clastic dikes cut across the diatomite beds, and these will give some trouble in getting out clean material. Closely spaced joints, in some places, will give trouble in trying to obtain good-sized blocks. Of course, for sacking material, such joints will make mining easier. The material is only slightly weathered.

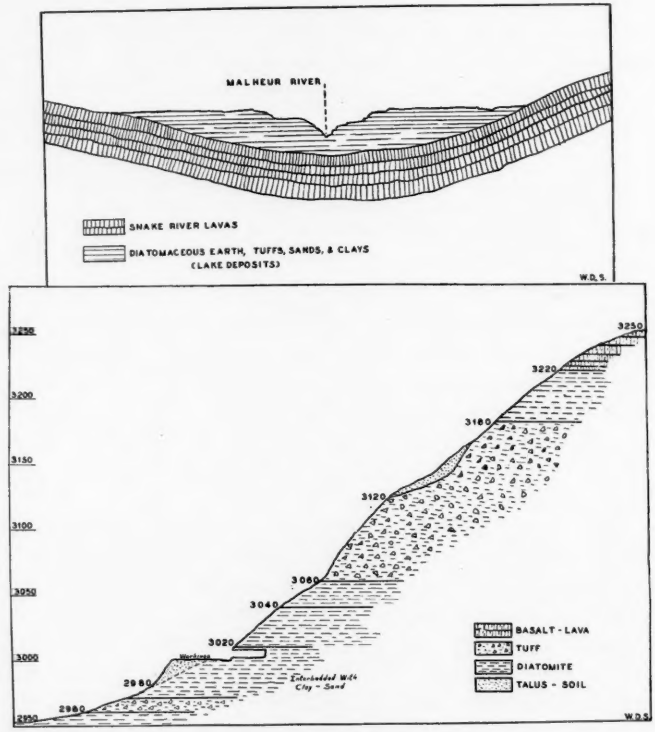

FIG. 2. Diagrammatic geologic section at Harper, Oregon.
FIG. 3. Detailed section at Harper, Oregon.

Petrology.

There are four important materials in this area which will be described in detail.

Diatomite.—This material is an organic sediment made up almost entirely of the silicious shells or tests of a microscopic plant known as the diatom. Mixed with it, in places, is a small amount of clay, or exceedingly finely divided ash, but in the commercial beds the material is fairly pure.

In all the deposits examined by the writer the diatoms are of two species, chiefly belonging to the same genus, namely, *Melosira granulata,* and *M. distans.* These can be readily seen with a field microscope magnifying two hundred diameters.

As these diatoms consist almost entirely of minute hollow cylinders, the porosity of the material is high. In one or two samples, the writer noted a few stray sponge spicules and a few fragments suggesting a different type of diatom, more like those found in the Deschutes River deposits, but in the main these were conspicuously absent. All the forms appeared to be clearly of fresh water origin. In some impure specimens, irregularly shaped, minute, fragments of volcanic glass were seen. In other specimens, cloudy patches can be seen under the microscope, indicating bits of clay mixed with the diatoms.

Diatomite, when pure, has the following specific physical properties, according to Eardly-Wilmot:[5] Luster—dull; sp. gr. 2.1–2.2 at 25° C.; apparent density 28–35 lbs. per cu. ft. (blocks); apparent density loose (8–16 lbs. cu. ft.); absorption 1½–3 times weight of water; melting point 1400–1750° C.; index of Refr. 1.44–1.46; thermal conductivity-powder 0.000 127 gr. cal. sec.; hardness 1–1.5.

Smith-Emery Company report that "blocks of this material can be burned at 2246° F. without cracking and with a linear shrinkage of but 5 per cent." Apparent sp. gr. is .575, equivalent to 35.8 lbs. per cu. ft. and a 34.6 per cent. increase in the addition of 10 per cent. diatomaceous earth. Mr. W. D. Wilkinson of our department of Geology has made some tests on our

[5] *Op. cit.*

material and finds the sp. gr. of the Harper diatomite to be 1.25; absorption, 137 per cent.; index of refraction, 1.469. The thermal conductivity at 35° C., as determined by Professor Caswell of the Physics Department, is as follows:

$$K = 0.92 \times 10^{-3} \text{ joules-cm/cm } 2^\circ \text{ C.-sec.}$$
$$= 0.22 \times 10^{-3} \text{ cal-cm/cm } 2^\circ \text{ C.-sec.}$$

There is one considerable discrepancy in these figures, namely, the sp. gr., which in the case of Wilmot's seems clearly to be in error.

Tuff.—Next to the diatomite, the most important deposit in this area, chiefly due to its effect upon the suitability of the diatomite for commercial purposes, is a tuff. This varies from an exceedingly fine-grained volcanic ash to coarse material, with occasional large fragments of volcanic rocks, approaching an agglomerate, in extreme cases. Commonly this material exists in distinct beds from less than an inch to several feet in thickness, and with a clean-cut separation from the diatomite.

The most conspicuous member in the tuff beds is a heavy-bedded, brownish-yellow tuff from fifty to one hundred feet in thickness, which marks a distinct separation between the " lower " and the " upper diato."

The finer material, which is generally of a bluish-gray color, has been given the field name of " silica sand," and needless to say, is deleterious to the diatomite, and must not be allowed to become mixed with it. Consequently, frequent microscopic examinations should be made of samples coming from these deposits. In general, however, the bulk of this material can be readily separated at the quarry by the workmen, and only the material from the thinner beds will have to be examined closely when brought to the mill.

Clay Beds.—Associated with the diatomite beds are also occasional thin clay beds which commonly have " frozen " contacts with the diatomite. However, they should not prove as troublesome as the ash beds.

Lava Capping.—Overlying all the formations of this area, there is a lava capping from one to thirty feet in thickness with, in some

places, a bed of tuff just below it. In most places, the lava is basalt; in others, it resembles obsidian. This lava capping is a part of what is known in Eastern Oregon as "rim-rock." Where it is thick, tunnelling beneath it may be necessary for the extraction of the diatomite.

Geological History.

The Snake River lava flows, whatever may have been their original position, have been folded and faulted.

FIG. 4. Diatomite at Terrebonne, Oregon.

Next, the diatomite, ash beds, and clay beds were laid down in one or more structural basins, and although there is a change in the character and coarseness of the material from the shore of the lake outward, the beds persist for considerable distances. An accumulation of ash in a side-hill outcrop, generally means that it is the edge of one of these beds, and must not be taken as merely a surface veneer. Because of lack of knowledge of the way in which the sedimentary formations were laid down, some wrong interpretations have been made, and superficial examinations have led to an erroneous estimate as to the amount of commercial

material; and the amount of impurities has been underestimated.

Three stages in the history of the deposits are of particular interest. First, the *deposition* of these materials, in more or less horizontal beds, with, however, an original gentle downward slope towards the center of the lake. Also many of the beds would be lenticular, and the coarser materials would be near shore and the finest silt out in the deeper part of the lake; therefore, horizontal changes in character of material and texture are to be expected.

The next stage is that of *deformation.* All these beds have been disturbed since their original deposition; there has been a certain amount of folding and fracturing, as already mentioned.

The third and last important stage has been that of *erosion,* dominantly by water action in the past, but latterly, perhaps, more through the agency of the winds. This has resulted in the topography previously discussed and has made the deposits readily accessible to excavation.

Chemical Composition.

An analysis of the diatomite selected from the commercial material is as follows: [6]

	Per cent.
Silica (SiO_2)	87.58
Alumina (Al_2O_3)	4.72
Iron Oxide (Fe_2O_3)	0.42
Lime (CaO)	0.76
Magnesia (MgO)	0.56
Alkalies ($Na_2O.K_2O$)	0.27
Sulphuric Anhydride (SO_3)	0.05
Chlorine (Cl)	None
Nitric Acid Redical (NO_3)	None
Carbon Dioxide	Trace
Organic Matter	None
Combined Water	5.64

This sample is a trifle higher in alumina than the best grade of Lompoc, California material, but compares favorably with the average material in the United States. In iron oxide it is even better than much of the material now on the market.

[6] Analysis of diatomite from Harper, by Smith, Emery Co., Los Angeles, Cal.

Commercial Value of the Harper Deposits.

Although the tonnage available at this site is not equal to the first estimates of the promoters, there is apparently an enormous supply of commercial grade material. Mining will not be as simple as at first thought, since stripping and steam shovel methods will not be everywhere feasible. The excellent grade of the material suitable for average purposes, accessibility and low humidity of the region give some advantages to the exploiters of this deposit. Some of the claims in this property are within a stone's throw of the railway.

THE TERREBONNE DEPOSITS.

At Lower Bridge, on the Deschutes River, in central Oregon (more exactly seven miles west of Terrebonne on the Dalles-California Highway) is found one of the best deposits of diatomite in Oregon, that of the Western Diatomite Company. At present this company is the most active of any attempting to commercialize deposits of this nature in the state.

As this deposit has already been well described in a recent report by Harold T. Stearns [7] of the Geological Survey, the present writer will not discuss it as fully as the Harper deposit.

Location.—The Terrebonne site is better than that of Harper in being closer to the West Coast markets, but on the other hand, it is not as close to a main line railroad. Climatically, the two sites are similar.

Geology.—The diatomite here occurs in essentially horizontal beds deposited in fresh water lakes in Pliocene or Pleistocene depressions in the Columbia Lava formation, and constitutes a part of what E. T. Hodge has named the Madras Formation.

The deposit has a maximum thickness, as known at present, of about 40 feet with an overburden of 12 feet of heavy gravel and light soil. The known deposit is one square mile in extent at least, but the writer believes test-pitting of the adjacent territory will reveal more ground underlain by this material.

[7] *Op. cit.*

Structure.—The writer saw no evidence of any disturbance of the original horizontal bedding. In this respect, and in the ease with which the over-burden can be removed, the advantages in favor of mining seem to rest with the Terrebonne locality.

ECONOMIC CONSIDERATIONS.

Uses.—The uses for this material are many, and new uses are being developed every day. Some of the most familiar uses are: (1) Polishing powder; (2) Fire-proof cement; (3) Boiler-backing; (4) Mixed with cement, producing a kind of Puzzualana; (5) As an ingredient of artificial fertilizer; (6) Manufacture of water glass; (7) Filtering material; (8) Insulation material for refrigerators, etc.; (9) Cosmetics; (10) Glazing materials.

The United States Bureau of mines[8] has a full statement on this subject, listing some ninety uses under the following general heads: (1) Filters, (2) Building materials, (3) Fillers, (4) Insulators, (5) Abrasives, (6) Absorbents, (7) Chemical reagents.

Professor H. D. McAlister of the Department of Mechanics and Astronomy, University of Oregon, made some researches on blends of diatomite with Olympic cement. He found that with one part of diatomite and two parts of cement, he got on a 7-day set, 356 pounds per square inch tensile strength as against 341 with the cement alone; on a 14-day set, 432 for the blend and 398 for cement; and in a 28-day test, 521 for the blend against 475 for cement. This indicates clearly one advantage at least in using this particular mixture. In compression tests the blend gave 4210 against 3030 lbs. per square inch after two months.

The apparent reason for this greater strength in the case of the blend is that the free lime in the cement combines with the silica of the diatomite to form calcium silicates that help to reinforce the mixture.

Smith-Emery Company, Engineers, of Los Angeles reported the following on this part of their tests made on the Harper material: "The tests made by adding [Harper] diatomaceous earth to a 1–3 mixture of cement mortar showed a 24.4% in-

[8] U. S. Bur. Mines, Rept. of Inves., Ser. No. 2718, 1925.

crease of tensile strength by a 5% addition of diatomaceous earth."

Markets.—This phase of the subject has been fully discussed by Lomax.[9] A few of the pertinent points are:

First, the local use of diatomite is at present extremely limited and consumption in Oregon will be a slow development owing to relative lack of manufacturing enterprises demanding raw material in this part of the United States.

Second, the distance from eastern markets and corresponding freight charges. If shipped by water through the Panama Canal, expensive extra-handling between freighters and steamers will add materially to its cost.

Third, competition with the "Celite" materials from Lompoc, California is an important factor in the development of the Oregon deposits. This Oregon material, like so many others in the State, depends for its commercial success upon the greater development of this region along industrial lines.

According to Lomax,[10] the Oregon product is worth $32 to $40 per ton in the Portland market. Freight rates from Terrebonne to New York are 75 cents for 100 pounds; to Chicago 65 cents, and to Portland 17 cents. Rates by water to eastern points are as low as 33 cents for 100 pounds on a carload basis.

In conclusion it may be said that diatomaceous earth is an important resource that exists in considerable quantity and of commercial grade, but that at present the demand for it is not quite sufficient for its exploitation on a large scale, owing to general tardy industrial development of this part of the country.

UNIVERSITY OF OREGON,
EUGENE, OREGON.

[9] *Op. cit.*
[10] *Op. cit.*, p. 158.

CARTOGRAPHY [1] FOR MINING GEOLOGY.[2]

HARRISON SCHMITT.

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[1] Cartography—The art of map making; Mapping—The act of making a map; Control—Any system of surveys on the ground or on a map that may be used as a base for further surveys or the measurement of geological data.

[2] Presented before the Society of Economic Geologists, Charlottesville Meeting, April, 1929.

INTRODUCTION.

THERE are definite signs of revolt in a certain school of geologists against the current methods and philosophy used in mapping the geology of ore deposits. The procedures adequate for regional mapping, non-metallic and petroleum geology are found unsuitable. Technique and methods have been described here and there in the literature, but have not been brought together into a system, neither have certain obvious refinements been generally adopted, such as the use of larger scales, and the "isolation of exposures method." Much of the effect of these is automatic, because by their use many supposed problems of the ground solve themselves. The "isolation of exposures" method [3] (5, pp. 194–5) [4] consists in mapping the solid rock as distinct from the mantle rock, which leaves an accurate record of the outcrops and gives a base for interpretation that can safely be used by geologists not personally familiar with the ground, and also lends meaning to the areas of mantle rock, for hidden dikes, intrusive, gossans or collapsed ground may be defined.

Another obvious but neglected refinement is enlargement of scale. Maps drawn on scales as large as 1 in. = 1000 ft. may be inadequate for directing exploration or recording the data obtained from special studies of gossans, alteration halos, or other features. Indeed, in places maps on scales up to 1 in. = 30 ft. on both the surface and underground are found to be appropriate. This is illustrated by Fig. 1, which shows three maps on different scales, of the same ground at Hanover, New Mexico, all now reduced to the same scale. The first map gave no suggestion of hidden ore, the next enlargement led to the discovery of ore, and the third map added new knowledge and led to the discovery of important additional ore.

The ore at Hanover favors a 50–100 foot limestone horizon and is searched for by diamond drilling. If every foot of ground penetrated is to count the holes must be kept near the intersection

[3] It may be called the "solid method" for convenience.

[4] Numbers in parentheses are references to the bibliography at the end of this article.

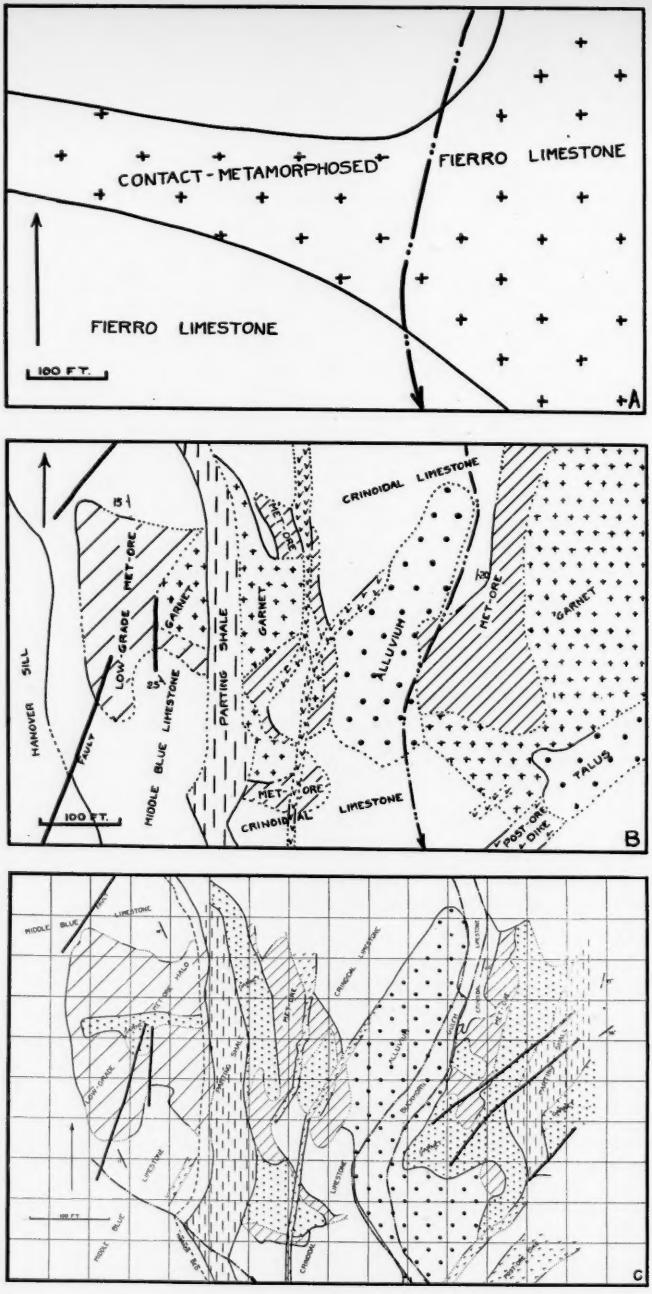

FIG. 1. Three maps of the same area: (*a*) was mapped on a scale of 1 in. = 10416 ft., (*b*) on 1 in. = 100 ft. and (*c*) on 1 in. = 30 ft.

of the favorable horizon with vertical fissures or other small targets. The accuracy needed was obtained by mapping most of the square mile or more of mineralized ground on a scale of 1 in. = 100 ft., but critical areas required a scale of 1 in. = 30 ft.

Some feel that field mapping is and should be largely inductive in method (5, pp. 189–195), for although brilliant and rapid advances have been made by deductive reasoning in geology in general, it is clear that imagination and speculation have had too much play in the mapping of many complex areas. Mining geologists in the West know at least a half-dozen mineralized areas that have been recently remapped and that yielded a picture with little resemblance to the earlier ones. Such contradictions are brought about by inadequate mapping methods and faulty philosophy, not necessarily by careless mapping.

PART I—ESTABLISHMENT OF CONTROL.

Claim Corner Method.

The surveys of patented mining claims may be used as a base for detailed geological mapping because they have been executed with a transit and the notes are usually available. The position of the claim corners can be calculated to coördinates and plotted on a map of any desired scale. This base can be supplemented by side traverses if elevations are obtained, and a geological map made that, under certain conditions, may be used to plan exploration for ore. To check the original survey, critical corners may be intersected with an alidade.

Open-sight Alidade and Brunton Compass.

A good detailed map can be made if a base line is measured and an open-sight alidade used for the horizontal control (15) and a Brunton compass for the vertical. Locations for observation are obtained by intersection or resection, and " three point " resections are particularly useful if the triangulation stations are widely separated and there is little intermediate control (18). Given a large limit of permissible error a compass may be used for orientation and " two point " resections made.

Topographic Base Map Method.

The small-scale topographic map, such as is used for the work of the U. S. Geological survey, is at present the favorite base for mapping in all fields of geology except petroleum. The scale is commonly smaller than 1 in. = 1000 ft. One of the most serious objections to the use of the small-scale topographic base map is that the structure cannot be shown in complete detail and features, which may have significant relations to ore, are blurred or lost by the generalization necessary.

No fixed method of mapping with topographic base is in common use; the procedure differs with the scale. When plotting geology on the small-scale maps few measurements are taken in the field unless the topography is flat and featureless, whereas with larger scales a plane table may be needed to establish locations. But in this case, because the map must be fixed to the plane table, the real advantage of the previously prepared topographical map, *i.e.*, that the sketching can be made directly upon it, is lost. This difficulty is partly eliminated if the topographers leave located stakes, but there is still a need for accurate locations and elevations on key beds, which can be satisfied only by locations established by the geologist himself. The " Hanover method " of mapping, to be described later, results in rod locations on key beds, but loses the advantage of direct sketching on a base map.

Standard Plane Table and Stadia Method.

The standard plane table and stadia method for establishing control has been well described. (See 15, 16, 17, 18.) The limit of error inherent in the method permits the base line to be measured roughly, therefore rapidly, with a cloth or steel tape, and expansion by triangulation can be made with the plane table and alidade. The ultimate control is established by resection, traversing, and radiation by stadia, and by radiation from stadia locations by Brunton compass and pacing traverse. Long stadia traverses are checked every tenth shot or so by resection and finally if possible by " closing."

Plane Table Technique.—A plane table outfit suitable for a

country of strong relief is composed of an alidade,[5] a Johnson head tripod, and two boards, one 18 by 24 inches for reconnaissance work, the other 24 by 31 inches for detail mapping. The map and the instrument men can be protected from the sun and rain by a simple canopy. In the New Mexico and Colorado highlands during the rainy season [6] this arrangement has proved to save about one-fourth of the working time.

The use of vertical angles and a stadia slide rule in place of the Beaman stadia arc permits the instrument man to release the stadia rod, and therefore the geologist, more quickly. This is important because the speed of mapping is commonly limited by the speed of the instrument work. With a little practice the instrument man should be able to make his calculations in the field, but he should check them later in the office.

Of all stadia rods that have been tried, most instrument men prefer the kind painted alternately black and white, at foot intervals, with 1/10 foot subdivisions at the 5 and 10 foot marks to facilitate reading in the woods.

The rod points are marked for future reference by small stakes or a small pile of rocks containing a numbered slip of tough paper. In Virginia, because of the dampness, this paper is put into one-ounce stoppered bottles. For instrument notes a separate notebook is kept for each plane table sheet, or loose leaves may be used. All the pages of instrumental and geological notes belonging to a given quadrangle or map are filed together.

The principal objection to the standard plane table and stadia method is that the stadia locations, which are established along with the observational work, are not immediately available for sketching geology unless the geologist returns to the table after each "shot." If the geology is relatively simple the notes can adequately describe the detail surrounding and connecting the

[5] One similar to the Gurley No. 582 is satisfactory.

[6] An excellent plane table paper is double mounted, green-tinted Dietzen No. 52 (16, p. 779). Water-proofing by painting with a mixture composed of 1 oz. of paraffin to 1 gal. of gasoline limits expansion and shrinkage, and is invaluable where a sudden shower may ruin an untreated map. Drying on frames for several weeks is a satisfactory treatment in the Southwest, but even there the paraffin can be added to advantage.

points of observation and the data can be plotted in their correct position on the plane table sheet in the office. If the geology is too complex to be described by notes, the geologist may plot by estimation each group of points in his notebook and then draw in the connecting detail. Later, when the plane table sheet is available in the office he may adjust his work to the true position of the points.

Hanover Method.

The standard plane table and stadia method is satisfactory in mining districts when scales of 1 in. = 200 ft. or smaller are adequate and when the area of interest can be mapped on one plane table sheet, but with larger areas and scales serious troubles appear. First, it is difficult to tie adjacent plane table sheets together (17, p. 633); second, greatly expanded plane table triangulation introduces errors beyond those permissible for most work; and third, no accurate locations can be left on the ground for diamond drilling, development and claim surveys, or for special larger-scale mapping of critical areas.

These difficulties are eliminated by the use of transit triangulation and traverse for the primary control. Then adjacent plane table sheets can be perfectly matched; in any given area errors of location are kept within the permissible limit; the control points, being expressed by coördinates, can be plotted on any number of maps of any scale; and finally a permanent control is available for any purpose.

The method of geological mapping here called the Hanover method is essentially a plane table and stadia method, but a base of transit triangulation and traverse is used (1, 2, 3, 5, 9) and the topography is mapped along with the geology. The scale is commonly greater than 200 ft. to the inch. Developed on the property of the Empire Zinc Co.[6] at Hanover, New Mexico, it was used for mapping several districts in the Southwest, the Bertha Mineral Co.[7] properties at Austinville, Virginia, and the Empire zinc Co. properties at Gilman, Colorado.

Once the triangulation net is established, a secondary control is

[7] Subsidiary to the New Jersey Zinc Co.

planned to meet local conditions. The triangulation stations are connected by chains of transit traverse stations (Fig. 2) located on ridges or open spaces, and in wooded country so placed that they overlook the opposite slopes and permit the stadia rod to be read in spite of the trees. The transit stations are heavy wooden

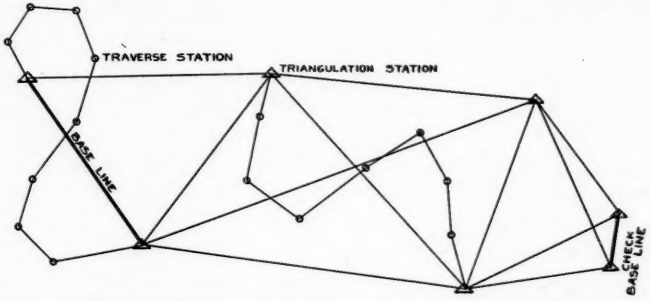

FIG. 2. Plan of a triangulation net which shows a "check" base line and "chains" of transit traverse stations.

stakes with attached numbered metal tags. In an area where surveying is to be done for several years steel pins set in the rock or soil are used for two or three adjacent stations.

Mapping Geology and Topography Together.

When a plane table and stadia method is used for detailed mapping, the topography may be economically mapped with the geology (16), for, with abundant geological detail, enough points will be located for the geology alone to permit the construction of a good topographic map. Only where the geology is simple will extra points be needed for topography. Commonly the points critical for topography are also critical for geology. In rugged topography with a minimum of located points it is good practice to draw the contour lines in the field, but if there is an abundance of points and the detail of the topography is described in the notes, the contour lines may be conveniently and no less accurately drawn in the office. On large scales with abundant points the drawing of contour lines becomes a mechanical process.

Modifications of the Hanover Method.

Grid Method.—When precise detail is wanted on large scales, such as 1 in. to 50 ft. or larger, it is often advantageous to map by what may be called the grid method. The area is laid out in 50 or 100-ft. squares; a numbered stake is located at each corner. The corners are plotted on a tracing, a white print is taken to the field, and the geology is plotted square by square. Additional measurements are made with a Brunton compass and a tape. Fig. 2-C shows an area mapped in this manner. Although more satisfactory for certain kinds of detail mapping than the plane table method, this has the disadvantage of the topographic base map method, *i.e.*, no observations for elevations are available along critical contacts such as key beds. Elevation is accurately known at the stakes only.

Infiltration Method.—When first beginning to map unknown ground, if the geologist does not wish to commit himself to mapping all parts of the area in detail, he may use what may be called the infiltration method. This consists in establishing precise control, covering the ground in reconnaissance, and locating critical points with the stadia rod. The first observations, although scattered, are taken with the degree of precision used for complete detail. This preliminary work will function as a reconnaissance and may indicate areas that need not be mapped further. But if the map requires completion in critical areas, the remaining detail can be taken and tied to the earlier observations (Fig. 3).

Comparison of Methods.—The claim corner base and open-sight alidade methods should be used in detailed study only where the more expensive methods cannot be considered. Of course, they may be adequate on simple ground where the area to be mapped is small or where the scale can be small. On average ground, however, where an adequate appropriation for mapping is available, either the topographic map method or the Hanover method is to be recommended. On unknown ground some expense may be saved by the use of the infiltration method, a modification of the Hanover method. On difficult ground the grid method is a useful auxiliary.

The choice between the topographic map method and the Hanover method depends on local conditions. Where expense is not a critical factor, the former with the modifications suggested will be better, particularly in difficult topography. Simple topographic forms and average geology, however, may be more economically mapped by the second method. Indeed, the cost

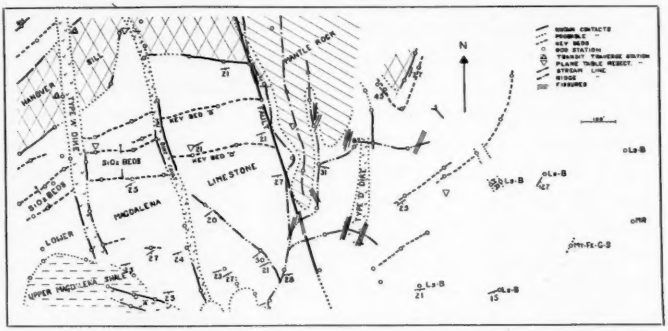

FIG. 3. A map which shows the stages in mapping by "infiltration." The area on the left is completed, that on the right is being invaded.

may be less than half, because with the first the ground must be gone over by both the engineering and the geological parties. The Hanover method is particularly advantageous where many key beds are to be followed.

Certain modifications of the plane table and stadia method and topographic map method have been considered but not tested by the writer. The objection to the plane table and the stadia method, that the geologist does not have a map to sketch upon, might be obviated by having the instrument man signal the coordinates of the stadia points at which the geologist has held the rod. A black-board and crayon could be used for signaling and the geologist could plot the points on a duplicate map and sketch in the detail.

The objection to the topographical map method, that accurate locations are difficult to obtain when the geology is being sketched on the original topographical map, might be overcome by the use

of a hand-sized range finder recommended by James Stuart [8] for measuring distances. Presumably he obtains the direction of the sighted point by compass, its elevation by interpolation on the topographical map.

Range finder sights on several located points might obviate the inaccurate compass observations needed with this method. In this case, a triangular or three legged rule with adjustable legs or a single-leg compass could be devised to simplify the plotting of the desired vertex of the resulting triangle. For any given location the legs would be set at the three known distances which would give directly the position of the desired point in relation to the base. If an accurate range finder is unavailable a small stadia telescope mounted on a light tripod (16, p. 780) might be made to serve. In this case permanent circular stadia rods would be set up on some of the prominent known points.

When a vertical angle to a known point exceeds five degrees it becomes necessary to reduce the inclined distance to the horizontal. An inclinometer could be attached to either the range finder or stadia telescope and each leg of the triangular plotting scale could be constructed as a small slide rule with a cosine or stadia scale, as the case may be.

PART II—COLLECTION AND SYNTHESIS OF GEOLOGICAL DATA.

Surface Mapping.

Symbols.—A system of quantitative symbols and abbreviations is a necessary accompaniment of any large-scale mapping method that emphasizes geological measurement. Obviously, precise quantitative mapping is only as effective as the mode of representation. A system used in the Southwest has the following essential features: The names of the common rocks and minerals are abbreviated to one or two letters, and symbols for modifications such as metamorphism or mixtures of types are connected to the primary symbol by a dash. For example, limestone wholly replaced by garnet is expressed *Ls-G*. But if there is also epi-

[8] Written communication. E. Leitz Inc., New York City, make a 40 cm. base, hand instrument, which they claim has a maximum error of 3 per cent. at 900 ft.

dote, less in amount than garnet, the combination is expressed by *Ls-G-E*.

If the geologist feels that he can safely estimate the proportion of the modifying minerals he may write *Ls-9G-1E*. Many other useful quantitative symbols may be devised. Notes on a completed map are generally inappropriate and suggest a weakness or incompleteness in the system used, besides taking up valuable space and detracting from the appearance. The ideal map would represent the facts and ideas as an immediately understandable quantitative composite.

When the geologist does not distinguish the known from the inferred on his map he is likely to forget the grade of probability of the first plotted observations before the map is finished, which gives rise to conclusions founded on badly mixed and uncertain facts and inferences. A map that clearly separates the known from the supposed, on the other hand, has full value to later users who can judge or modify or add to the first interpretations to suit their own opinions or needs. Following this idea the large-scale field maps made for a zinc mining company express facts only. The interpretations are drawn on supplementary or office copies, whereas the originals are filed for future reference and mapping. The field maps are not necessarily completed. If mapping is to be carried on for several years in the same area it may be a mistake to try to complete at once difficult ground which may appear quite simple when studied over a long period.

Stratigraphic Section Measurement.—The section must be studied and measured in detail where sedimentary or bedded volcanic rocks are important. Perhaps only through experience can the geologist realize the time to be saved by doing this first and thoroughly. The accuracy of a structure contour map, for example, is increased in proportion to the amount of detail worked out on the section.

Brunton Method of Hayes and Hewett.—In an area of simple structural conditions, where the limit of permissible error is not less than 10 per cent., the Brunton method devised by Hayes and modified by Hewett is convenient and fast (2, pp. 23–27; 3, pp.

371–372). Only a Brunton compass and a table of coefficients are required. Where the line of measurement is parallel to the direction of the dip a number of dip observations are taken and averaged, and the compass clinometer set at this average. The instrument is then held to the eye, the level bubble centered, and a sight taken down the dip. The point sighted is stratigraphically above the observer, the height of his eye times the cosine of the dip angle. A table on which this formula is worked out for each degree of dip up to 45, with the height of the observer's eye a constant, is convenient. Then when measuring a section, the stratigraphical thickness is the number of "sights" times the proper coefficient from the table.

The Hayes and Hewett method is slow and inefficient for dip angles greater than 45° and its accuracy is limited to the accuracy of the dip measurement. On poor outcrops it is often impossible to get an accurate dip observation with the Brunton compass.

Plane Table Method.—By measuring the section with plane table or transit traverse parallel with or at a small angle to the dip, greater speed, if no greater accuracy, is obtained. This method, however, if dependent on Brunton compass dip measurements, may result in an error greater than the limit set. Except for increased speed, therefore, the full advantage of the plane table or transit for stratigraphical section measurement is not obtained unless the dip of the beds is determined by three-point solutions. Three points are located—by stadia usually—on the same sedimentary horizon (Fig. 4). Two may be on or near the same strike line, but the third should be as far up or down the dip as possible—three points on the same line cannot be used, neither is an approach to this condition satisfactory. In order to get well separated points, both horizontally and vertically, on the various beds, sharp ridges or arroyos nearly parallel to the dip should be taken advantage of. In this way dip and stratigraphical thickness can be obtained with less than a five per cent. error.

The use of charts for reducing traverse measurements of sections that run at an angle to the dip direction is well known. J.

B. Mertie has prepared a chart for this and it is reproduced by Hayes (2, pp. 27–28). It should be noted that in all section measurement the critical factor is the accurate measurement of the dip.

The methods described above may result in serious errors if faults, sharp folds, unconformities or other disturbances have not been disclosed. The remedy may lie in making a complete detailed map of the ground along the section. From three to six

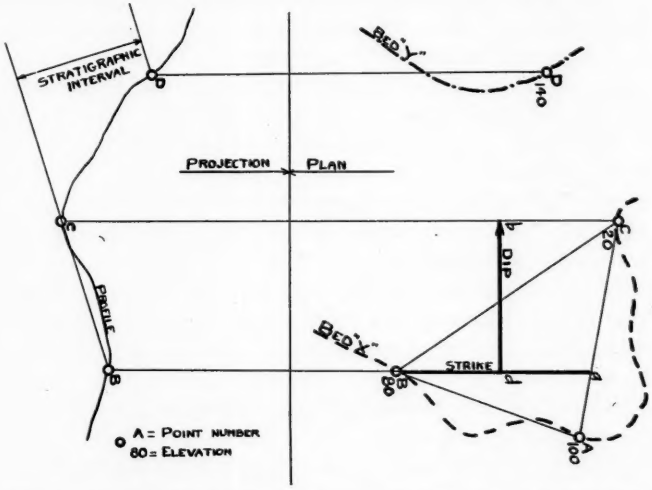

FIG. 4. Illustrating dip and stratigraphical thickness by the three-point method.

measurements at different places, the number depending on how badly the country is disturbed, will be needed to obtain a satisfactory mean for a given section.

General Suggestions.—When a satisfactory section has been measured and the geologist is intimately familiar with the position of each key bed and sedimentary contact, he may start the geological mapping. The location of partly concealed cross-cutting features such as dikes, faults and veins, except those whose trace

is parallel to the bedding, will be revealed by following key beds with the rod. The trace of those parallel to the bedding, in turn, will possibly be revealed by following the contacts of the across-bedding cross-cutting features (Fig. 3).

Where a dike or sill is covered by mantle rock, but occasional ribs outcrop, the dip and strike may, in places, be revealed by the "sympathetic" fractures parallel to the contacts. These fractures are caused by flow lines, shrinkage or post-intrusion shear. When mapping a dike, it is advisable to record at each point of observation the width, change in type, and degree of metamorphism and alteration. At a certain "contact-metamorphic" deposit in the Southwest, epidotic alteration of a dike commonly means nearby ore, whereas sericitic alteration is unrelated to ore.

When tracing faults one should not interpret too freely and should remember that commonly they are not regular planes and that their variation may have significance. For example, in at least two silver districts in Mexico, ore shoots are related to concavities in the footwalls of fault-veins.

When tracing veins, all mine openings, the width of the vein from place to place, dip and strike and all changes in mineralization should be measured and recorded. The type and amount of voids, gossans and wall rock alterations are of particular importance. Certain gangue minerals intimately associated with ore are resistant and remain in the outcrop after all of the other minerals have been leached. They may make valuable criteria. For example, in the Parral district, Chihuahua, Mexico, fluorite and voids in an outcrop usually mean ore below (6, p. 287).

Strict attention must be paid to the topography and mantle rock. In the Parral district, Chihuahua, the oreshoots are surrounded by masses of silica, with the result that most of the important ore shoots outcrop on elevated places. The intershoot areas are commonly loci for arroyos (6, p. 287). In the Little Florida Mountains, New Mexico, strips of mantle rock (talus largely) about ten feet thick cover the outcrops of manganese veins collapsed because of solution. The wall rocks are resistant and always outcrop. The veins were discovered not through

outcropping ore, but by determining that the strips of mantle rock marked faults. At Hanover, New Mexico, the zinc ore outcrops are covered by mantle rock, the wall rocks are bare. In general then, dikes, sills, intrusions, gossans and collapsed areas are in places disclosed by the patterns of mantle rock that cover them and, in detailed work, mantle rock must be mapped as carefully as any other lithologic unit.

Caliche [9] is locally a criterion for ore in northern Mexico and the Southwest and must be observed and mapped. A patch of caliche was the only surface expression of the Ahumada-Erupcion manto oreshoot. Indeed, a majority of the mines and prospects in the Southwest have caliche as an intimate associate of the gossan; few districts that have been visited lack it. Long narrow bands of caliche, up to 3 feet thick, cap the veins in the Cordero district, southern Chihuahua.

Dips and strikes of beds and contacts comprise a large proportion of observations made and should be taken with care because the accuracy of structural work depends upon them. To obtain a satisfactory mean in any given small area, it may be necessary to take three or more observations. Where the exposure is good, an acceptable observation may be obtained by placing the eye in the plane of the bed and then sighting on the bed with a Brunton compass. Where the strike and trace of the plane of a fault, vein, or contact, do not coincide, it may be advisable to record both and represent them on the map.

When starting to map, much is gained by deferring the classification of the rock units until all the field work and microscopical and chemical work can be done. In the field the units may be called *A, B, C,* etc. Then, when defined (*A* and *B* may be combined or *C* divided) and a representative sample obtained, final identification and classification is carried out. These key letters may be used for symbols on the final map, or to make patterns if the map is not colored.

Detailed mapping, particularly on large scales and complicated ground, commonly requires some " specialization of the moment,"

[9] $CaCO_3$, minor $CaSO_4$.

for if, at the same time, the geologist should attempt to record data on gossan identification, metamorphic or alteration halos and, oxidation collapse, he would find that his ideas would become confused and his work inefficient. There would be too many things to be kept in mind at once to do justice to any one of them. The first mapping ought to be confined to structure, leaving the specialized studies to be taken up one by one on the same ground. The first survey leaves a control of stakes or other marks on the ground to which the later specialized observations can be tied without the need of an engineer at a plane table because a copy of the original map can be used and the specialized detail sketched directly upon it.

Underground Mapping.

Scale.—The scales used for underground work are relatively large, varying between the extremes of 1 in. = 10 ft. to 1 in. = 100 ft. Where an average amount of geological detail is to be mapped a scale of 1 in. = 25 ft. is satisfactory (11).

Drifts and Cross-cuts.—When mapping drifts and cross-cuts (15, p. 118) it is common practice to use a white-print of the mine level as a base map, which preferably shows all details of the outline of the drifts and all survey points. The practice of washing the walls before the mapping is started (12, p. 675) has been particularly effective at Austinville, Virginia and should be extended. Underground mapping should be done on a previously selected horizontal plane; the one that cuts the drift waist-high is the most accessible. Observations are located by measuring from the nearest survey plug. In complicated ground, where the walls are dirty, accuracy and speed are gained by marking with a lamp the critical contacts as they are traced out.

Raises, Winzes, and Stopes.—Methods used to map raises, winzes, and stopes vary greatly. Where the openings are straight the data can be projected to a plane passing through the centerline. Stopes and crooked raises and winzes can be conveniently surveyed by using the German or miners compass and inclinometer. Traverses are run and side measurements made by means of a string tightly stretched between nails driven into the walls. The

bearing and inclination of this string or "shot" are obtained by a compass, and a clinometer with a free-swinging arm. Both instruments are suspended from the string.

Two clinometer readings should be taken from opposite ends of the tautly stretched string and their average will be the correct angle of inclination, thus eliminating the error caused by the catenary sag.

An underground traverse is surveyed with the miners' compass as it would be by a transit, *i.e.*, consecutive "shots" are taken and side traverses run where needed. An error of less than one per cent. is not unusual, but all the traverses ought to be closed. One of the advantages is the ease with which "side-shots" can be made, for, the line of traverse being fixed and visible, side measurements can be taken in any direction with a tape or folding rule. The shape of the mine opening and the geology can be recorded at the same time.

General Suggestions.—The final office copy of an underground geological map does not differ greatly from the original sketch. Some data not pertinent are left out, whereas certain interpretations are added, but notes should be omitted unless certain features cannot be expressed by symbols.

Synthesis.

Cross-sections.—The most useful cross-section is made through the best known country. Placing sections on a geometrical pattern is advisable only where the geology is simple. When compiling a cross-section, the components of the dips of intersecting planes can be obtained by formula or by the usual charts. If the intersection of one cross-section with another is plotted on both, the interpretations can be readily compared and tied together. Sections are improved if nearby mine workings are projected to them.

Structural Contour Maps.—Most geologists are familiar with structure contour maps. These are especially valuable in mining geology (10, 19), where ore follows definite horizons. To be effective, greater accuracy is needed than for oil-field structure,

for example, and the following suggestions are given with that in mind.

When the surface geological map is made and key beds are followed and located at regular intervals with the stadia rod, two purposes are served if as many points as possible are spotted for the determination of dip and strike by the three point method. First, with these accurate dip determinations, a given stratigraphical interval can be obtained with a small limit of error by compiling a number of cross-sections, up to ten possibly, along the strike, all of which are concerned with this one interval only. Large variations from the mean are thrown out and the final mean is accepted as the standard interval. Second, because it is directly dependent on the local dip, the local vertical distance to the contoured horizon can be determined accurately.

At this stage a tracing is made on which are plotted all observed dips and strikes, key horizons with the points located on them, and the traces of all known faults and igneous contacts. The intersections of cross-cutting contacts or faults with the contoured horizon—disclosed by underground development—are shown by distinctive lines projected to the horizontal plane. Then at each point the vertical distance to the contoured horizon is computed by dividing the stratigraphical interval by the cosine of the dip. This distance subtracted from the elevation of the point gives a corresponding elevation on the horizon to be contoured. Elevations obtained in this way and the observed strikes form the basis for drawing the contours.

The final map is usually a print from the original tracing. The contours, key beds, contacts and faults are differentiated by color or by different types of lines. The reading of a contour map, where the fault structure is complicated, is made easier by coloring or patterning a selected bed.

Special Maps, Charts and Curves.—Where the basic data of measurement and observation are quantitative, many useful syntheses can be made which include equal-ore-width maps, curves showing variation in rocks caused by metamorphism, and charts showing variation in gossans or significant gangue minerals such

as fluorite and quartz. The intensity of fissuring may be represented by counting the number of fissures per unit of length and plotting a curve.

Equal-ore-width Maps.—Equal-ore-width maps have been previously described (4, p. 321). The known parts of an ore body are represented on any convenient plane of projection by lines connecting "points" of equal width. Such a projection may be useful in predicting ore-shoot extensions or giving information on the "shape-habit" of ore bodies.

Equal-ore-value Maps.—In equal-ore-value maps (4, p. 320), the known parts of an ore body are represented on a convenient plane of projection by outlining areas of equal value. Indirectly, equal-value lines are thus derived. Such a map often gives important information on ore-shoot extensions and the effect of oxidation, leaching and enrichment.

Curves Showing Variation of Metal Content.—Curves showing variation in metal content in various directions in mines could be advantageously used to a greater extent in problems of leaching, oxidation, enrichment, primary zoning and extension of ore shoots (14, p. 410; 6).

ACKNOWLEDGMENTS.

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EL PASO, TEXAS.

BIBLIOGRAPHY.

1. BREED, C. B. & HOSMER, G. L.: Elementary Surveying. John Wiley & Sons, Inc., New York City, 2 vols., 1918.
2. HAYES, C. W.: Handbook for Field Geologists. John Wiley & Sons, New York, 1921.
3. LAHEE, FREDERIC H.: Field Geology. McGraw-Hill Book Co., New York, 1923, New ed., 1931.
4. SCHMITT, HARRISON: Extension of Ore Shoots, etc. Trans. Am. Inst. Min. Eng., 1929.

5. GREENLY, EDWARD, AND WILLIAMS, HOWARD: Methods in Geological Surveying. Thomas Murby & Co., London, 1930.
6. SCHMITT, HARRISON: Geology of the Parral Area of the Parral District, Chihuahua, Mexico. Trans. Am. Inst. Min. Eng., pp. 268–290, 1931.
7. ——, Geologic Notes on the Santa Barbara Area in the Parral District of Chihuahua, Mexico. Eng. and Min. Jour., vol. 126, p. 410, 1928.
8. BANCROFT, HOWLAND: Am. Inst. Min. Eng., Bull. 91, 1914.
9. BIRDSEYE, C. H.: Topographic Instructions of the United States Geological Survey. U. S. Geol. Surv. Bull. 788, 1928.
10. FOWLER, G. M. AND LYDEN, J. P.: The Ore Deposits of the Tri-State District. Am. Inst. Min. and Met. Eng., Tech. Pub. 446, 1931.
11. GILBERT, D. C.: Mine Maps. Eng. and Min. Jour., vol. 132, pp. 18–20, 1931.
12. BROCK, R. W.: Scientific Ore Finding. ECON. GEOL., vol. 19, pp. 674–676, 1924.
13. MCKINSTRY, H. E.: A Protractor for Plotting Dips on Inclined Sections, ECON. GEOL., vol. 18, pp. 393–397, 1923.
14. RANSOME, F. L.: The Copper Deposits of Ray and Miami, Arizona. U. S. Geol. Survey, Prof. Paper 115, pp. 144–145, 1919.
15. ——, The Plane-table in Detailed Geological Mapping. ECON. GEOL., vol. 7, pp. 113–119, 1912.
16. PELTON, E. F. AND IRWIN, D. D.: The Plane-table in Geologic Mapping. ECON. GEOL., vol. 7, pp. 778–783, 1912.
17. WEGEMANN, C. H.: Plane-table Methods adapted to Geologic Mapping. ECON. GEOL., vol. 7, pp. 621–637, 1912.
18. HIGGINS, D. F.: The Plane-table in Geological Mapping, with especial reference to graphic horizontal control by intersection methods. ECON. GEOL., vol. 8, pp. 729–751, 1913.
19. HEWETT, D. F.: Geology and Ore Deposits of the Goodsprings Quadrangle, Nevada. U. S. Geol. Survey, Prof. Paper 162, 1931.

RELATION BETWEEN SILVER CONTENT AND TETRAHEDRITE IN THE ORES OF THE NORTH CANANEA MINING CO., CANANEA, SONORA, MEXICO.

HARRY V. WARREN.

INTRODUCTION.

THIS paper is one of a series that deals with the occurrence and distribution of the precious metals in the ores of some important base metal mines in western North America.

The mine of the North Cananea Mining Company is situated about four miles north of the town of Cananea, Sonora, which is about twenty-five miles south of the International Boundary, and is connected by railroad with Naco and Nogales, Ariz., and by motor road with Naco and Bisbee.

ORE BODY.

The ore is found in shoots that occur irregularly along nearly vertical fissures, which cut a series of pyroclastic rocks known as the Mesa tuffs and andesites. As no high temperature minerals or evidences of marked thermal metamorphism are found in or along the margins of the ore bodies, and as the mineral association is that usually ascribed to medium or medium-low temperature ore bodies, they are tentatively assigned to the mesothermal type of hypogene fissure deposit.

Age of Mineralization.—The Mesa tuffs and andesites are members of a well recognized series of rocks which are definitely Tertiary in age. The mineralization is therefore Tertiary in age.

Minerals Found.—The hypogene minerals are few in number. Galena and blende, both coarsely crystalline, are the most abundant metallic minerals. Chalcopyrite is conspicuous in some places, but more commonly it is found in small particles associated

with tetrahedrite, which is usually inconspicuous but is persistent throughout the better mineralized portions of the lodes. Pyrite in small amounts is irregularly scattered throughout the ore. Both blende and the galena show evidence of having been subjected to pressure, the blende by twinning and the galena by bands showing parallel cleavage.

Quartz and calcite occur, but in most of the shoots the ore consists of massive crystalline sulphides without gangue. In some places the ore occurs as a part of the cement of a breccia, and here too there is a paucity of introduced gangue.

The similarity between some parts of this description and that of the mine of the Calumet and Sonora Company as described by S. F. Emmons [1] is most striking and suggests that a group of deposits of the fissure type lie along the outskirts and are related to the disseminated copper deposits of the main Cananea District.

Paragenesis.—The paragenesis of the minerals is confusing because a megascopic examination indicated that the tetrahedrite is younger than the galena and the blende. However, polished sections show that galena veins tetrahedrite. There may have been some overlap in the crystallization of these minerals and possibly there were two generations of tetrahedrite, although no proof of this could be found. Pyrite appears to be the oldest mineral; then blende was introduced, followed by tetrahedrite, chalcopyrite and, lastly, galena.

Distribution of the Silver.

Galena, blende, tetrahedrite, and chalcopyrite were separated in turn and then assayed, polished sections of each mineral being examined.

Tetrahedrite.—This mineral proved to be not only difficult to separate, but also the richest precious-metal carrier. Enough of this mineral was obtained for only one complete analysis, and this gave an unsatisfactory total, but it is sufficiently accurate to indicate the value of the tetrahedrite as a precious metal carrier. The analysis is as follows:

[1] Emmons, S. F.: Econ. Geol., vol. 5, pp. 351–352, 1910.

Sulphur	24.55
Silver	6.55
Copper	30.66
Zinc	7.70
Arsenic	.32
Antimony	23.20
Iron	1.70
Lead	1.65
Silica	.10
Manganese	trace
Cadmium	trace
	96.43

Manganese, cadmium, silica, iron, and lead are almost certainly impurities. Polished sections show that the iron is probably due to chalcopyrite and possibly to pyrite. The lead is beyond doubt due to included galena.

In order to recalculate the composition of the tetrahedrite by removing the lead and iron, it is necessary also to remove sufficient sulphur and copper to satisfy galena and chalcopyrite, which contain 2.30 per cent. S., and 2.03 per cent. Cu.
The corrected analysis of the tetrahedrite is therefore:—

Sulphur	22.25
Silver	6.55
Copper	28.63
Zinc	7.70
Arsenic	.32
Antimony	23.20
	88.65

After recalculating to approximately 100 per cent., the analysis is then brought to atomic proportions:

Sulphur	$= 25.05 \div 32.0 = .784 =$	.78 (77) (7)	
Silver	$= 7.38 \div 108.0 = .068 =$	.57 (55) (6)	
Copper	$= 32.30 \div 64 = .505 =$		
Zinc	$= 8.68 \div 65.4 = .133 =$	.13 (11) (1)	
Arsenic	$= .36 \div 75 = .005 =$	.22 (22) (2)	
Antimony	$= 26.16 \div 120 = .218 =$		

This analysis is not sufficient to yield a definite formula of this

mineral. However, the close relationship between this analysis and many others of tetrahedrite shows conclusively that it belongs to this group, although it is unusually high in silver and zinc and somewhat low in copper. If the atomic proportions given in the parentheses are assumed, the formula is $(Cu_2Ag_2)_2(AsSb)_2S_6$, ZnS. Nevertheless, whatever the formula may be, it is evident that the presence of a small amount of the mineral will cause the ore to be rich in silver. It will be noted that the approximate percentage ratio of silver to copper is 1 : 4.5 and of silver to antimony 1 : 3.5.

Galena.—The problem of whether or not the galena carries silver is of extreme importance because galena, like blende, is much more abundant than the tetrahedrite.

An analysis was made of as pure galena as it was possible to obtain with the following results: Pb, 86.09 per cent.; Zn, trace; Cu, .12 per cent.; Fe, trace; As, trace; Sb, .12 per cent.; Ag, .079 per cent.

The trace of iron probably represents a trace of chalcopyrite. The .12 per cent. of both copper and antimony suggests strongly the presence of some tetrahedrite. Taking the mean ratio of silver to these minerals—about one to four—it can safely be assumed that about $(.12 \div 4) = .03$ per cent. of silver is due to this mineral. There is left only .049 per cent. of silver unaccounted for; this presumably represents the amount of silver present in chemical combination with the galena. Consequently it is certain that the galena in the North Cananea carries only .049 per cent. of silver, which is considerably less than the proportion of silver contained in the galena of most rich silver-lead ores such as those of the Park City District of Utah.

Blende.—Two analyses were made of zinc blende which was obtained in as pure a state as possible. "*A*" represents blende of the "rosin" type and "*B*" represents some of a black variety.

	A	*B*
Zinc	65.21	62.30
Copper	trace	1.03
Iron	1.58	1.11
Lead	.02	—
Silver	.003	.18

"*A*," which is obviously almost pure material, contains such a negligible amount of silver as immediately to rule out zinc as a source of silver. A portion, if not all, of the iron present is due to the presence of pyrite.

In "*B*" the silver appears to be high, but it will readily be seen that the sample is by no means as pure as "*A*," the zinc content being only 62.3 per cent. Furthermore, it seems probable that three-quarters or even more of the iron is due to pyrite. Then, even if traces of chalcopyrite account for 25 per cent. of the copper content, there is still left adequate copper to account, in the form of tetrahedrite, for all the silver reported. The powder from the sample was examined before analysis and did show particles of chalcopyrite and tetrahedrite. Thus, in this district at least, there seems to be little doubt but that blende carries no silver chemically combined, all the silver being present as inclusions of tetrahedrite. It is also interesting to note that the "pure" blende carried .33 per cent. of cadmium.

Chalcopyrite.—Relatively pure chalcopyrite yielded: Copper, 33.20 per cent.; Iron, 30.80 per cent.; Silver, .009 per cent. This shows conclusively that chalcopyrite is unimportant as a silver carrier.

Pyrite.—As pyrite could not be isolated in quantities sufficient for analysis, a conclusive statement can not be made. However, its occurrence in blende does not add to the silver content appreciably and probably it is safe to exclude pyrite as a silver carrier.

DISTRIBUTION OF THE GOLD.

Gold has not been seen megascopically or microscopically and consequently its mode of occurrence must remain conjectural. However, numerous assays show clearly the distribution of the gold.

The following assays show the number of ounces of gold per ton found in each of the four important sulphides:

Blende	.000 ozs.
Galena	.010 ozs.
Chalcopyrite	.012 ozs.
Tetrahedrite	.400 ozs.

Thus there is little doubt but that the gold is associated with the copper and particularly with the tetrahedrite. The small amount of gold found with the galena is due in all probability to the impurities previously discussed.

CONCLUSIONS.

The gold and silver in the ores of the North Cananea Mining Company are related to the copper which was deposited in the form of chalcopyrite and tetrahedrite, the precious metals being almost exclusively related to the latter.

Like the ores in the Ruby district, the galena is later than the copper minerals, which were introduced after the earlier sulphides, blende and pyrite, had consolidated and been fractured.

The intimate manner in which the sulphides are found in the 350-foot level, the deepest part of the mine accessible during my visit, the lack of other copper minerals in the ore that could be altered to chalcopyrite or tetrahedrite, and the complete lack of any evidence of alteration by descending solutions in the main pockets of lead and zinc ore, imply that the chalcopyrite and tetrahedrite, like the galena and the blende, are hypogene in origin and will probably persist to such depth as the lead and zinc persists.

The tetrahedrite contains over 7¼ per cent. silver and in the form of minute specks in the galena is responsible for at least a part of the silver found in that mineral, which, in fact, carries not more than about .05 per cent. silver.

The chemical composition of the tetrahedrite is such that it is inevitable that the higher the silver content of the lead concentrate, the greater will be the amount of zinc, arsenic, antimony, and copper present. Furthermore, it is certain that zinc and chalcopyrite are of no importance as carriers of the precious metals. Galena probably carries no gold but does carry some silver.

The tetrahedrite at this mine contains an unusually high percentage of silver and zinc, and a detailed description of this variety will be presented in another paper.

ACKNOWLEDGMENTS.

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I wish to express my thanks to the North Cananea Mining Company and especially to Mr. C. W. Gabrielson, Mr. F. L. Harrington, and Mr. John A. Campbell who, together with their staff, coöperated whole-heartedly in the securing of the necessary specimens.

I also wish to thank Dr. F. L. Ransome and Mr. R. Engel of the California Institute of Technology for their invaluable help, advice, and criticism in the preparation of this paper.

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GENESIS OF THE DEPOSITS OF AURIFEROUS JACUTINGA.[1]

EUZEBIO P. DE OLIVEIRA.

In a recent trip to Minas Geraes, I visited several gold deposits in the Municipalities of Marianna, Sabará, and Caeté, especially those of auriferous jacutinga, which form a type peculiar to this country. Unfortunately, the renowned mines of Gongo Socco and Maquiné were inaccessible.

Character of Deposits.—Descriptions of these deposits have been made by Eschwege (1),[2] Henwood (2), Hocheder (3), Gorceix (4), Hussak (5), and others.

Professor Gorceix (4, 74) says:

> In the itabirites, . . . exist gold deposits, whose disposition is peculiar to Brazil and which have no analogy with other gold deposits in the world. The gold appears to be irregularly disseminated in the body of the rock in form of plates . . . which may be aggregated to form thick nuggets; however . . . the rich trends show a definite direction as in a vein.
>
> In these deposits, the complete absence of sulphides, which exist in large amounts below the itabirites, is remarkable. The only substance that . . . seems to indicate the presence of gold, is a white lithomarge that forms small spots within the rocks.

The genesis of these interesting deposits has not been studied. Dr. E. Hussak (5, 96, 97) in his paper on palladium says:

> The itabirites are free from pyrite; commonly they are cut by narrow veins and stringers of quartz, strongly undulated. . . . These rocks should be considered as a metamorphosed sediment (limestone).
>
> The deposits, in the shape of nuclei and bands in the itabirite, must be regarded as jacutinga. They have a thickness of only 50 cm. and are characterized by a high gold content, by absence of pyrite, and by the occurrence of talcy or clayey nuclei with dusty pyrolusite. They vary in mineral composition. . . .

[1] Revised by L. B. Riley and the Editor.

[2] Numbers in parenthesis refer to bibliography at end of paper.

The difference in the mineral composition of the decomposed jacutinga seems to indicate two different modes of genesis. . . . In the itabirite, there are commonly narrow deposits of decomposed limestone rich in magnetite and silicate of magnesia, suggesting that part of the nuclei of jacutinga must be contact metamorphic limestone. . . . The other nuclei of jacutinga, rich in micaceous clay and containing tourmaline (with cassiterite), may have a granitic origin.

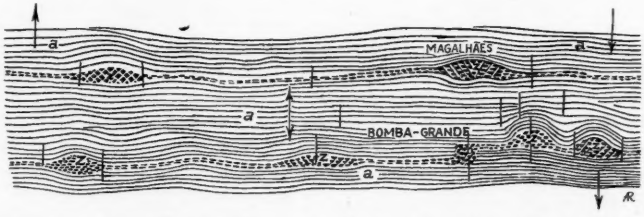

FIG. 1. Agua Quente or Bananal. Horizontal section of the jacutinga. *a*, laminae of specular and micaceous iron ore; *o*, auriferous deposit on a cross-vein; *z*, auriferous masses of (jacutinga) brown iron ore, manganese, talc, quartz, and oxidized iron. After W. J. Henwood.

The greater part of the gold in these deposits occurs in nuggets, lumps, slags and lines, in the so-called *lode;* about one third of it occurs disseminated in smaller grains. No reasonable explanation has been advanced for the great richness of the jacutinga in gold, and for the occurrence of the associated minerals. Also, in these deposits there is always manganese (generally pulverulent), talc, lithomarge, and brown earthy iron ore, as well as specular iron ore.

The jacutinga deposits follow the stratification of the itabirites, the gold being disposed in parallel bands or zones that alternate with quartz or even with the itabirite proper. They exhibit a decidedly sedimentary character.

Origin of Deposits.—Percolating waters containing O and CO_2 attack the pyrite, the more important final products being ferric sulphate and sulphuric acid. Thus, the oxidation of the sulphides brings about a residual enrichment of gold which because of the temporary inhibition produced by ferrous sulphate does not go into solution but remains behind as a very fine dust. The

oxidation of the pyrite ends in a pseudomorphous limonite after pyrite. The limonite encloses gold plates, showing that within the crystal there occurs a certain transportation of gold.

In the oxidation of the pyrite sulphuric acid is formed, and as most mine waters contain some NaCl, the following reaction may take place at the temperature of the ground water:

$$2\ NaCl + H_2SO_4 = Na_2SO_4 + 2\ HCl$$

Since MnO_2 exists in the itabirite formation, either in the form of valuable deposits or disseminated in the rock, then it should react with the HCl according to the well known equation:

$$4HCl + 2MnO_2 = MnCl_2 + 2Cl + 2H_2O.$$

As gold dissolves in nascent chlorine, the fine gold of the pyrite will be dissolved by Cl producing $AuCl_3$ and the MnO_2 will become $MnCl_2$. These reactions have been verified by W. H. Emmons (6) and especially by A. D. Brokaw (7).

It should be noted that ferrous sulphate, in the presence of an excess of MnO_2, is almost immediately changed into ferric sulphate, and so the precipitation of the gold of $AuCl_3$ is delayed or made impossible. Therefore, gold in the form of $AuCl_3$, in presence of MnO_2 remains in solution due to the absence of $FeSO_4$. It is enabled in this way, to pass to the lower parts of the formation until the excess of acid is reduced, the iron and manganese tending simultaneously to hydrolize and to deposit oxides. In this stage the $FeSO_4$ content increases and this salt actuates precipitation of the gold.

Gold transportation is thus dependent on the oxidation of ferrous sulphate by manganese dioxide. In presence of MnO_2, gold may also be conducted downward and be deposited below the water level. A slight enrichment of gold may be found in the lower part of the oxidized zone. In zones of great oxidation, superficial concentrations of gold may be encountered at all levels.

The solution of $AuCl_3$ with $MnCl_2$ moving downward, may, if it encounters organic matter, H_2S, carbon, sulphides, tellurides or carbonates, be precipitated from the chloride solution. In this

manner the association of MnO_2 with gold in the jacutinga deposits is fully explained.

The presence of lithomarge is explained by alteration of the feldspar of the pegmatites.

The presence of talc in auriferous jacutinga deposits is explained by alteration of amphibole or other magnesia-bearing minerals. Some granites yield talc, and it is possible that the talc of jacutinga is from this source. It may be pointed out that the talcose schists of the old geologists are really sericitic schists, as was proven by H. Gorceix; but as Dr. Hussak mentions talc in the deposits of auriferous jacutinga, it must be supposed that this mineral is found in these ores.

Some of the best descriptions of auriferous jacutinga deposits support the theory of origin advanced above. For example, Hocheder (3), states:

> The most important part, however, in places made up of several layers each scarcely thicker than paper, in other places forming a single bed varying from a fraction of an inch up to three or four, but rarely six inches in width, and conforming to every flexure of the rocks adjoining—occurs near the middle of the series. Of the narrow portions, earthy brown iron and manganese are the chief ingredients; in the others, the ores commonly are associated with specular iron or hematite. . . . In both cases it is difficult, if not impossible, to distinguish the auriferous band from other strata.
>
> About the middle of the disintegrated specular hematite schist, manganese renders this part, known by its brownish-black color and greater softness, more or less distinct from the rest of the formation. These distinct layers of jacutinga form the *lode*, in which the great riches of Gongo Socco occur. . . .
>
> Wherever hard, crystalline, massive hematite touches or approaches the auriferous bands, these cease to be productive. . . . In parts of the productive layers where no gold is visible to the naked eye, it exists disseminated through the jacutinga (p. 15).

Indeed, the general dispersion of gold in the itabirite had previously been noted by several persons who know these deposits.

In my recent excursion I verified the presence of gold in the itabirite at the following places: Tinoco mine, near Marianna; S. João do Morro Grande, a dust iron ore (itabirite) used in the

blast furnace of the iron plant; Ria Una, at its left bank, where it is crossed by the road from Santa Barbara to Itabira; Ouro Preto, in an outcrop near the Escola de Minas. Besides these, the presence of gold has been shown in the itabirite at more distant places. The occurrences are, therefore, widespread. It is to be observed that the jacutinga deposits are always located within the itabirite formations.

The manganese performs two important functions in the superficial enrichment of the gold deposits: it aids the solution of gold in cold, dilute, surface waters, and it impedes the precipitating agency of the ferrous salts, and thus permits the gold to migrate downward before its final deposition. In deeper zones, where the solutions attack other minerals, the waters lose their acidity, and then the manganese compounds, under stable oxidizing conditions, are precipitated with the gold.

Conclusions.—In conclusion, it may be stated that:

1. The gold of the jacutinga is of secondary origin, that is, it is derived from solution and precipitation of gold from pyrite quartz veins.

2. The manganese dioxide, lithomarge, and limonite result from the above mentioned reactions.

3. The absence of pyrite in these deposits is now explained.

4. At depths below the water-table, the tenor of gold of these deposits must diminish rapidly.

5. The best guide for detecting gold deposits in the itabirite formation is the pulverulent manganese dioxide.

6. It is not possible for gold to exist in jacutinga where there are no auriferous pyrite quartz veins, that is, primary deposits.

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BIBLIOGRAPHY.

1. VON ESCHWEGE: Annales des Mines, VIII, pp. 401–430; Pluto brasiliensis, pp. 210–215.
2. HENWOOD, W. J.: Edinburgh New Philosophical Journal. L., p. 61. Edinburgh, 1851.

3. Hocheder, T. C.: Brazilian Mining Association Rept. XV (1833), p. 54.
4. Gorceix, H.: Estudo chimico e mineralogico das rochas do centro da Provincia de Minas Geraes. Annales da Escola de Minas, No. 1, pp. 1–12. Ouro Preto, 1881.
5. Hussak, E.: O palladio e a platina no Brasil, pp. 77–189. Annales da Escola de Minas. No. 8. Ouro Preto, 1906.
6. Emmons, W. H.: The Agency of Manganese in the Superficial Alteration and Secondary Enrichment of Gold Deposits in the United States. Am. Inst. Min. Eng. Bull. 46, pp. 789–791, 1910. The Principles of Economic Geology, pp. 405–411, 1918.
7. Brokaw, A. D.: The Solution of Gold in the Surface Alterations of Ore Bodies. Jour. Geol., vol. 18, pp. 321–326, 1910.

DISCUSSION AND COMMUNICATIONS

THE OUTLOOK FOR COPPER (NOTMAN).

SINCE the appearance of Mr. Notman's paper in this journal,[1] the copper mining industry of the United States has secured a temporary respite from the influx, both threatened and actual, of foreign copper through the inclusion of a four cent excise tax on the metal in the revenue bill. It is realized by the domestic industry that in order to be saved, copper must in the future be protected by a tariff. The present excise tax is simply a temporary emergency expedient.

The arguments for and against tariffs in general are voluminous and more or less familiar to all, and have no place in this journal. It is felt, however, that Mr. Notman has not been entirely impartial in his statements regarding the copper tariff and that some comments of a non-technical nature are therefore due the readers of ECONOMIC GEOLOGY, whatever their nationality, who are not familiar with the point of view of the American copper producer.

In the first part of Mr. Notman's paper, statistics are quoted which are interpreted as showing the "short-sighted greed" of the copper producers in the years 1928, 1929 and 1930. One of the points raised is that the profits per pound of copper during those years were excessive. However, if these profits are recalculated on the basis of their commodity values, it is apparent that the profit per pound of copper in those years was worth but little more in terms of commodities than in the average year since 1861. The figures are given in the following tabulation.

The remarks on the last two pages of the article regarding the efforts of the domestic producers to secure tariff protection are to be criticized, because standing as they do without amplification

[1] Vol. 27, no. 3, May, 1932, pp. 219–230.

Period.	Bond Interest and Dividends Paid per Lb. Copper (Notman).	Wholesale Commodity Index (U. S. Dept. Labor).	Value of Bond Interest and Dividends Paid in Terms of Commodities.
1861–1865....	4.48¢	94.3¢	4.75¢
1866–1870....	1.24	99.8	1.25
1871–1875....	7.22	81.9	8.81
1876–1880....	4.95	65.0	7.62
1881–1885....	3.68	62.4	5.90
1886–1890....	2.91	56.7	5.13
1891–1895....	2.69	51.6	5.21
1896–1900....	5.32	50.0	10.64
1901–1905....	3.19	58.7	5.43
1906–1910....	4.06	65.6	6.19
1911–1915....	3.74	68.3	5.48
1916–1920....	6.30	125.5	5.02
1921–1925....	3.14	99.3	3.16
1926–1930....	4.47	95.2	4.70
1928.....	3.85	97.7	3.94
1929.....	5.93	96.5	6.15
1930.....	4.97	86.3	5.76

or supporting evidence, they contain assumptions, some contradictory, concerning which there is a difference of opinion and considerable evidence leading to other conclusions. Mr. Notman does not make it clear that the generally accepted processes of economic readjustment which will cure the present ills of industry as a whole and which he recommends to the copper industry, offer but little toward the cure of the more fundamental ills of the domestic copper producer due to the menace of foreign competition. Furthermore, he believes that the protection of American dollars invested in the exploitation of cheap labor and natural wealth in foreign lands is of equal or greater importance than the protection of the American workman developing at home the resources of the United States. Quotations from Mr. Notman's article follow, along with comments upon them.

> Those producers who are now asking for help from the public's pocket never raised a protest against the unwarranted profits that poured into their treasuries in 1928 and 1929 any more than they did over the war profits.

Surely the fact that the copper producers participated in the past prosperity along with the rest of the country is no reason

why they should refrain from seeking to be granted the protection which this country offers as a matter of self interest and self protection to its industries, especially those called essential industries, when their existence is threatened by foreign competition. Furthermore, the writer does not feel at all convinced that the 1928 and 1929 profits were unwarranted in view of their comparative commodity purchasing return.

There is just as great an excess of domestic capacity over probable normal domestic consumption as there is of foreign capacity over probable foreign consumption.

It is the very fact that the recent threatening excess of foreign capacity over probable foreign consumption has developed which makes the tariff imperative. The assumption that there is an excess of domestic capacity over probable normal domestic consumption in no way relieves the domestic producer from the overhanging threat of the ability of the foreign excess to control the domestic market. With the proper tariff in effect, domestic producers would have the opportunity to work out their own domestic problems. Without it they have no such opportunity. Without it, commercial agreements in regard to production would be necessary between the American producers and the foreign. Each and every agreement would be hopelessly involved with the national policies of Canada, Rhodesia, Belgium, Spain, Mexico, Peru, Chile, and others, and in the present frame of mind in which the world finds itself it is questionable whether such agreements, even if reached, could be carried out over a period of years. National interest is everywhere the rule, and there is no use in trying to blind ourselves to that fact. International considerations will not prevent the United States copper market from falling into the hands of any but the lowest bidders.

A tariff can not be made effective without a conspiracy among the domestic producers to withhold output.

The situation could be much more fairly stated as follows: With an adequate tariff, the United States producers would be in a position to work out the policies by which they could legally ad-

vance the welfare and the security of the domestic industry. They would be in a position to take advantage of any modifications and more liberal interpretations, of laws which have held over from the old anti-trust days.

If such a conspiracy were legal, it could not be enforced among companies whose costs vary from 5½ cents to 12 cents per lb. to produce the metal.

This is of course purely an assumption. The picture is not necessarily one of a group of six-cent producers putting a group of ten-cent producers out of business. Moreover, the ore reserves of the lowest-cost producers in the United States are among those most definitely known. They may be large, some of them, but they are not in the same class in size or richness with some of the foreign copper deposits. At any rate, to reiterate, why should the luckless medium-cost domestic producer be forced to compete with the whole world simply because he must compete with certain domestic producers whose costs are lower than his?

In fact, a tariff would do the domestic industry just about as much good as a tariff on wheat did the wheat farmer.

If Mr. Notman is right in supposing that the tariff would do the domestic industry no good, why does Peru believe that the tariff would damage her industry by cutting down her income and throwing her men out of work? Foreign Minister Rosell of Peru is quoted as follows:[2]

We are engaged in a frank open struggle with United States Congress. Passage of proposed duty on copper would mean absolute ruin to Peru and Chile.

Why do certain foreign producers distribute anti-tariff literature to their stockholders? Why in conferences of the world copper producers was the threat of a tariff successfully used in bringing foreign producers to listen to reason? Why are there threats of retaliation? Why, during the recent discussion of the excise tax in Congress were certain foreign producers busily moving vast stocks of unsold copper across the borders into the United

[2] Boston News Bureau, May 14, 1932, p. 3, quoting Lima special to Times.

States? Why does the opposition to the tariff come so strongly from those interested solely in foreign mines?

It has been stated on good authority that the late Smoot-Hawley bill raised the tariff on some 800 articles; it would be pertinent to ask how many of those have escaped the depression.

Are the manufacturers of these articles asking congress to stop the depression by repealing the tariff? Does any one contend that a tariff on anything will be a factor in guaranteeing the protected articles against the vicissitudes of the business cycle? The plea for a tariff on copper has come at a most inopportune time, because of this very confusion of thought which ascribes the troubles of the copper producers solely to the depression and ignores the fact that the flood-waters of devastating foreign production are mounting. When the recovery starts in and the demand for copper increases, is this country willing to trust to the effectiveness of informal international producers' agreements to preserve an essential industry?

All the companies now appealing for help from the public's pocket had an equal opportunity to secure an interest in these foreign resources with those who were successful in so doing. Had they done so, there would be no tariff agitation now.

This is commendably frank. It pictures the advantages secured by those successful in obtaining interests in the foreign deposits and admits that those with such interests do not desire a tariff. Why not? But the fact that certain companies preferred to attempt to find and develop new mines within the United States is no reason why they should refrain from asking for protection against the production of others who went outside the borders to develop the foreign industry. As a matter of fact, their efforts at home entitle them so much the more to protection. They are under no gentlemen's obligation to be " good sports " and accept defeat from those who were successful abroad. On the contrary, those who put up their money to develop a foreign industry to compete with that of the United States must expect the stay-at-homes to take advantage of the protection which the government grants them.

Mr. Notman quotes J. R. Finlay, with approval.

Then the folly of creating prosperity by restricting trade on the part of nearly all the nations; . . . This tariff agitation for copper is just another example of the crowning vice of this country. Namely, that small interested minorities by force of clamor and publicity succeed so often in putting over schemes that are absolutely contrary to the public interest.

But at the present time is the status of international good will and mutual trust among the nations such that any country can afford to take a chance on abandoning the policies which promote national industrial independence? If not, measures insuring this independence, including tariffs, are not "contrary to the public interest." They are, on the other hand, necessary for the public welfare. And when the governors of 12 of the most important copper-producing states sign an appeal for tariff protection, the implication is unjustified that it is a case of a small interested minority putting over an unpatriotic scheme.

It is an American industry regardless of where its investments lie.

Mr. Notman, in an address before the New York chapter of the Mining and Metallurgical Society of America, Nov. 24, 1931, expanded this statement. In order to show just what he means by it, and to make clear how he regards it as being related to the tariff question, some of his remarks on that occasion are quoted.[3]

There is one respect, however, in which the supply of copper in the world is unique. This fact entitles it to particular consideration in relation to tariff policy. Practically the entire copper production actual and potential of Canada, Mexico, and South America, and 40–50 per cent. of that in Rhodesia is owned by companies all or the great majority of whose stockholders are citizens of the United States, entitled to the same consideration at the hands of the Government as others. Through the courage and enterprise of those associated with or trained at the domestic industry, we have secured 75 per cent. ownership in the world's supply of this important metal in peace and war. Such a predominating control of an essential raw material is unique. It is obvious that there are many more American stockholders in International Nickel, Noranda, Hudson Bay, Chile, Andes, Braden, Cerro de Pasco, American Metal, and Newmont, to name the more important foreign units owned in this

[3] Notman, Arthur: A Copper Tariff. Min. and Met. Soc. of Amer. Bull. 222, vol. XXIV, no. 7, p. 104. Dec., 1931.

country, than there are employees engaged in purely domestic production. However little entitled to respect or protection stockholders in copper companies may appear to be at the present time, as American citizens in whose prosperity, the country is vitally concerned, they are entitled to equal consideration at the hands of our Government.

The meaning of these statements is unmistakable. It is that the American investor in foreign mines is entitled to equal consideration with the investors and employees in domestic mines. The American investor in foreign mines who did not go into these ventures with a realization of the logical sequence of events, indeed finds himself in an embarrassing position in this tariff situation. He begins to realize the significance of what was said long ago to the effect that where a man's treasure is, there his heart is also. He finds his competitor, the domestic producer, coming forward to claim the right to participate in the protection which the traditional policy of the United States provides for its home industry against those who threaten it from without. He knows that the United States regards this policy of protection as essential to its safety and to the public interest. And yet we see some cases where he frantically attempts to deprive the domestic producer of his recognized rights and his country of the direct control of one of its essential industries, by the specious claim that because he is an American citizen the foreign industries which he develops are by the same token " American industries " also. Anyone who follows recent studies of the economic aspects of the mineral industry of the world knows that the national interests of the countries in which mineral deposits lie are, in the final analysis, in a position to dictate the policies of exploitation, regardless of where the capital investment may be. C. K. Leith in his recent articles brings this forcibly before us as a fact to be faced, regardless of our personal feelings of the wisdom of such nationalistic policies. He says:

Certainly the world has not reached the Utopian condition where any nation can be expected voluntarily to yield up to any super-national body the ownership of a part of its resources.[4]

[4] Leith, C. K.: The Political Control of Mineral Resources. Foreign Affairs, July, 1925, pp. 15–16.

In nearly all parts of the world governments are tightening their control of mineral resources, in a great variety of ways. . . . The explorer of today contemplating activities in any foreign country will do well to study all the political complications before starting. In almost every country he will run afoul of new political measures designed to secure national political control.[5]

This might be pursued further but enough has been said to justify the question: "In these days of increasing national control of mineral resources throughout the world what right has the American investor in foreign copper mines to demand that the United States government grant him special privilege by abrogating in the case of copper its policy of protecting its national interests?" It is not the American producer who is "appealing for help from the public pocket book" but the American investor in foreign mines who wants, for his express financial benefit, to have the government abandon the policies which it has established to insure national welfare and security.

Mr. Notman closes with a recommendation that the industry submit to the general methods of cure which it is hoped will be effective in bringing industry as a whole out of the depression. These are well tried cures and will doubtless work in ordinary cases. But they will not solve the outstanding problem of the domestic copper industry, and the reasons why should be apparent to one who has read the foregoing.

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[5] Leith, C. K.: Mineral Exploration. ECON. GEOL., vol. XXVI, no. 3, May, 1931, pp. 335–336.

REVIEWS

Jahrbuch des Deutschen Nationalen Komitees für die Internationalen Bohrkongresse, Band II. (Yearbook of the German National Committee for the International Drilling Congresses, vol. 2). Pp. 360, many illus. Berlin, 1932.

The year book contains the following papers: (1) A. Bentz, The Different Oil Horizons of Northern Germany, Their Primary or Secondary Origin (pages 21–109, 22 maps and figures). Benz gives one of the best and most up-to-date descriptions available of the occurrence of oil in North Germany. In conformity with the prevailing mode of thought in Germany, he concludes that the oil deposits in general are secondary and that the oil originally came from the Permian beds below the salt series. The conclusion that the secondary origin of most German oil deposits has been demonstrated is vigorously opposed by Stutzer and by Kauenhowen in the discussion which follows Benz's interesting paper. (2) E. H. W. Zaeringer, The Importance of the Drilling Technique in the Freezing Method of Sinking Shafts (pages 111 to 128). (3) H. Reich, What Rôle Does Geophysics Play in Drilling for Oil (pages 129 to 158). This excellent résumé paper will be of interest to American geologists and geophysicists mainly for the discovery torsion-balance map of the Sugarland salt dome. (4) W. Halder, three papers, The Problem of Drilling Mud (pages 159 to 190), A New Depth Record, Jardin No. 35 (pages 191 to 204), Technical Data in Regard to Three Very Deep Wells (pages 205 to 214). (5) W. Kauenhowen, The East Texas Oil Field; Studies of the Greatest Present-Day Oil Field in the World (pages 215 to 260, 34 illus.). Kauenhowen gives an interesting all-around description of the field and the drilling and production practice in it. The reviewer recommends it to graduate students who are interested in oil and scientific German, not only for practice in reading and translation but for an interesting survey of this important oil field. (6) E. Fulda, Mining Laws in the Oil Regions of the World (pages 260 to 290). (7) A. Hoffmann, Progress in the Production of Oil (pages 291 to 314). (8) Good English abstracts of the papers (pages 317 to 327). (9) Abstracts of the papers in French (pages 328–339).

DONALD C. BARTON.

HOUSTON, TEXAS.

The Unstable Earth. By J. A. STEERS. Pp. 341, figs. 66. E. P. Dutton & Co., New York, 1932. Price, $4.30.

There has long been a need for a book which will summarize, for the benefit of the non-specialist, the current theories of geo-tectonics from a more or less neutral standpoint. This book fulfills such a need, in part.

The author has divided his material into two main sections; the first on the Earth's surface and its more important features, the second on recent changes of sea level. Of these the first is treated very generally and the second in much greater detail, with the result that the book appears to lack balance. It is, however, the author's thesis that a study of recent oscillations of sea level will throw much light on such questions as isostasy and the subsidence of land bridges. More information on these questions will, of course, aid in the discussion of the contraction and drift theories.

It is very easy to point to many errors of omission in a book of this kind, but the author could hardly have compressed more material into it than he has done without seriously affecting his very readable style. As it is, he has attempted quite successfully to present in about two hundred pages an analysis of the earth's features, shields, geosynclines, mountain systems, oceans, island arcs and submarine canyons, together with an account of the Earth's structure, illustrations of the structures of mountain ranges, and recent theories (including a discussion of the theories of Chamberlin, Kober, Jeffreys, Wegener, Gregory, Joly, Daly and Holmes).

In his preface, the author expresses the hope that he has "correlated sufficient material to induce the student to consult the original references from which I have freely drawn, and to pass on from them to other works,—and, perhaps, his own work." The reviewer feels that this hope will probably be better realized if the student first attempts to study and digest one of the more pretentious works, so as to familiarize himself with the exact significance of the new terms which he must assimilate, before attempting to read a book in which these terms cannot be adequately defined for lack of space. With this background, he will find "The Unstable Earth" a very valuable aid in viewing the work of the author he has been studying in its proper perspective, and by constant reference to this book he will probably save himself from becoming confused by other theories as he extends his reading.

W. V. HOWARD.

URBANA, ILLINOIS.

Das Rhenium. By W. SCHRÖTER. Pp. 59. Ferdinand Enke, Stuttgart, 1932. Price, 5.50 Rm.

In the seven years since the discovery of the 75th element in platinum ore, a considerable body of information concerning its properties has been

accumulating, but has heretofore been scattered through many different publications, some of which are difficult of access. This information has now been assembled by the author in the pamphlet under review, for the convenience of chemists, mineralogists, and geochemists. The richest sources of the element thus far discovered are native platinum, gadolinite, molybdenite and lead selenide, from certain localities. After briefly outlining the history of the discovery of the metal, the author describes the method employed in isolating and purifying it, gives a summary of the properties of the element and its known compounds, discusses the analytical methods applicable to its detection and determination and concludes with a theoretical explanation of its origin and an explanation of its occurrence in platinum, sulphides and oxides.

A bibliography of 63 entries follows.

W. S. BAYLEY.

A Manual of Determinative Mineralogy, with Tables. By J. VOLNEY LEWIS. 4th edition, revised by A. C. HAWKINS. Pp. 230, figs. 76. Wiley & Sons, New York, 1931. Price, $3.00.

This is a worthwhile revision of a well known book for the determination of minerals based on their physical properties, blowpipe and chemical properties, and optical properties. The material has been revised and brought up to date, repetitions eliminated from the tables, rare minerals eliminated from the blowpipe tests, and a chapter added on optical methods. The tables are handy, the glossary is valuable, and the book is a convenient one for ready use.

Geological Society of South Africa, Index for Transactions and Proceedings, Volumes 14 (1911) to 31 (1930). By A. L. HALL. Pp. 478. Johannesburg, 1932. Price, 25/.

This valuable 20-volume index to the worthy publications of the Society is in four parts. Part I. is an alphabetical list of authors with the titles of their papers in the 20 volumes. Part II. is a list of illustrations in order, and Part III. is an alphabetical subject index to the illustrations —a new and convenient feature. Part IV. is the alphabetical subject index, painstakingly done and abundantly cross-referenced.

It is an index that should be in every geological library since it constitutes a reference to extensive and valuable geologic data.

The recently published 20-volume index (336 pages) of ECONOMIC GEOLOGY for 1905 to 1925, compiled by J. M. Nickles, may be obtained for $3.00 from W. S. Bayley, University of Illinois, Urbana, Ill.

BOOKS RECEIVED.

By

DAVID GALLAGHER.

Quaternary Geology of Minnesota and Parts of Adjacent States. By F. LEVERETT AND F. W. SARDESON. Pp. 149, figs. 24, maps 4, pl. 1. U. S. Geol. Surv. Prof. Paper 161. Washington, 1932. Detailed and extensive treatment of the glacial geology of this classic region.

Geological Importance of the Lime-Secreting Algæ, with a Description of a New Travertine-Forming Organism. By M. A. HOWE. Pp. 13, pl. 1. U. S. Geol. Survey, Prof. Paper 170-E. Washington, 1932.

Mineralogy of Drill Cores from the Potash Field of New Mexico and Texas. By W. T. SCHALLER AND E. P. HENDERSON. Pp. 124, pls. 39, figs. 18. U. S. Geol. Surv. Bull. 833. Washington, 1932. Price, 60 cts. Paragenesis and mineralogy, especially optical and chemical, of the many salt minerals of this important occurrence. Excellent photomicrographs.

Nitrate Deposits of the United States. By G. R. MANSFIELD AND L. BOARDMAN. Pp. 107, pls. 11, figs. 13. U. S. Geol. Surv. Bull. 838. Washington, 1932. Price, 40 cts. Geology of nitrates and descriptions of all known occurrences in the United States.

Gold Mining and Milling in the United States and Canada. By C. F. JACKSON AND J. B. KNAEBEL. Pp. 151, figs. 54. U. S. Bureau of Mines, Bull. 363. Washington, 1932. Price, 15 cts. Current practices and costs.

A Study of High-Manganese Slags in Relation to the Treatment of Low-grade Manganiferous Ores. By C. H. HERTY, JR., J. E. CONLEY, AND M. B. ROYER. Pp. 36, figs. 14. U. S. Bureau of Mines, Tech. Paper 523. Washington, 1932.

Summarized Data of Tin Production. By J. B. UMHAU. Pp. 34, figs. 13. U. S. Bureau of Mines, Economic Paper 13. Washington, 1932. World production over many years.

Molybdenum. By A. V. PETAR. Pp. 38. U. S. Bureau of Mines, Economic Paper 15. Washington, 1932. Covers all phases of the subject.

A Method of Estimating Ground-Water Supplies Based on Discharge by Plants and Evaporation from Soil. By W. N. WHITE. Pp. 105, pls. 10, figs. 29. U. S. Geol. Surv. W. S. P. 659-A. Washington, 1932. Results of Investigations in Escalante Valley, Utah.

Surface Water Supply of Hawaii. By N. C. GROVER. Pp. 101. U. S. Geol. Surv. W. S. P. 695. Washington, 1932. Gaging-station records, July 1, 1928 to June 30, 1929.

Surface Water Supply of the United States, Water Supply Papers, U. S. Geol. Survey. Gaging-station records. **1930,** Part 2, W. S. P. 697; Part 12, W. S. P. 708.

Cinnabar in Southwestern Arkansas. By G. C. BRANNER. Pp. 51, pls. 38. Ark. Geol. Surv. Information Circular 2. Little Rock, 1932. Price, $1.20. Fine treatment of the geology and origin, and description of the deposits, of this very interesting new occurrence. Such immediate action by a Geological Survey Department is to be highly commended.

Effects of Water-Flooding on Oil Production from the McClosky Sand, Dennison Township, Lawrence County, Illinois. By A. H. BELL AND R. J. PIERSOL. Pp. 26, figs. 9, tables. Illinois Geol. Surv., Press Bull. Series, No. 22. 1932.

Illinois Mineral Industry in 1931. By W. H. VOSKUIL AND A. R. EICH. Pp. 49, tables 28. Illinois Geol. Surv., Report of Investigations No. 25. Urbana, 1932. A preliminary statistical summary and economic review.

Ground Water Supplies of the Passaic River Valley near Chatham, N. J. By D. G. THOMPSON. Pp. 51, figs. 9, pl. 1. Dept. of Conserv. and Devel. New Jersey, Bull. 38, 1932.

Pennsylvania Caves. By R. W. STONE, E. R. BARNSLEY, W. O. HICKOK, 4TH, AND C. E. MOHR. Pp. 143, illus. 68. Topog. and Geol. Surv. Bull. G-3, Dept. of Internal Affairs, Comm. of Penn. Harrisburg, 1932. Popular description of caves, with brief portion on cave origin.

Geological Map of Pennsylvania. Topog. and Geol. Surv., Dept. of Internal Affairs, Comm. of Penn. Harrisburg, 1932. Scale 6 miles = 1 inch, full color. Large part of the map compiled from most recent data.

Gold in Canada. By A. H. A. ROBINSON. Pp. 92, tables 39, figs. 8. Canada Dept. Mines, Mines Branch, No. 730. Ottawa, 1932. Price, 20 cts. General treatment of gold and gold mining in Canada, and descriptions of Canada's chief producing gold mines.

Die geologische Erforschung Thüringens in älterer Zeit. By B. v. FREYBERG. Pp. 160, figs. 11, pls. 8. Gebrüder Borntraeger, Berlin, 1932.

Annuaire 1932: Comité d'Études Minières pour la France d'Outre-Mer. Pp. 375. Paris, 1932. Committee organization, legislation, colonial mineral statistics.

Mineral Resources of the United States, 1929, Part I—Metals. Pp. 967, fig. 1. Price, $1.50 (cloth). **Part II—Nonmetals.** Pp. 858, figs. 57. U. S. Bur. of Mines, Washington, 1932.

SCIENTIFIC NOTES AND NEWS

R. W. Brock, dean of the faculty of applied science at the University of British Columbia, has again gone to Hong Kong to complete for the British War Office the geological survey which was initiated several years ago. His work in economic geology will be carried on during his absence by Victor Dolmage.

W. Baragwanath, formerly director of the Geological Survey, Australia, has now been appointed Secretary of Mines, Victoria, Australia.

J. M. Boutwell recently visited New York and New Haven, having motored from Salt Lake City, and has been to Washington to confer with officials regarding the International Geological Congress meeting next year.

T. C. Phemister, professor of mineralogy, University of British Columbia, is now on leave of absence, and his work will be carried on by Harry V. Warren.

Bruce L. Clark, of the University of California, gave three lectures before the Geological Club at Yale University on November 17–18.

George H. Garrey, who was seriously injured in an automobile accident recently, is undergoing treatment at the Presbyterian Hospital, Denver, Colo.

G. C. Bateman, of Toronto, Canada, was a recent visitor in New Haven, and gave a talk before the class in economic geology at Yale University on the gold deposits of Ontario.

John B. Stone, of Pueblo, Colorado, was recently married to Sara Bailey Moulton.

S. A. Judson is vice-president of the Houston Geological Society for 1932–33.

John F. Graham has completed the survey of gold deposits near Hillsboro and in the Percha district, New Mexico.

A. Beeby Thompson, of London, who has been adviser to the Egyptian Government on petroleum for twenty years, has lately been decorated with the Order of the Nile, third class (commander), by King Fuad, in recognition of his services.

E. W. Todd, assistant manager, Lake Shore Mine, Kirkland Lake, Ontario, has resigned.

Leon J. Pepperberg, consulting geologist and engineer, has re-opened his office in Dallas, Texas, and will specialize in petroleum and natural gas problems.

The Kansanshi copper mine, in Northern Rhodesia, adjacent to the Belgian Congo border, was closed down in November due to the present copper situation.

The Society of Economic Geologists will not hold its regular meeting with the Geological Society of America during the Christmas vacation, as usual, but its annual meeting will be held at Princeton, New Jersey, on July 7–8, in order that foreign members arriving to attend the International Geological Congress may have an opportunity to participate.

The Geological Society of America will hold its 45th annual meeting on December 28–30 at Cambridge, Massachusetts. Headquarters and sessions will be at the Harvard Union. The presidential address, by R. A. Daly, on "The Depths of the Earth," will be delivered on December 28, at 8 P.M. The smoker will follow, and the dinner will be on December 29.

Sidney Powers, of the Amerada Petroleum Corporation, Tulsa, Okla., president of the American Association of Petroleum Geologists, died suddenly on November 5th, in a hospital at St. Louis, Missouri, having failed to rally after a gall bladder operation. He was one of the most active workers in the field of petroleum geology, and one who through his broad scientific interests served as a liaison between the Geological Society of America, the Association of Petroleum Geologists, and the Society of Economic Geologists. His untimely death at the height of his career is not only a blow to all his many personal friends but a great loss to the science of geology.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

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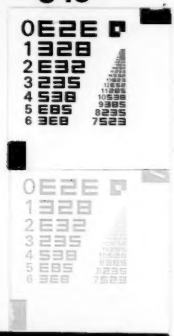
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